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Physiological Adaptations to Concurrent Muscular Strength and Aerobic Endurance Training in Functionally Active Adults with a Physical Disability

by

James Jay Laskin ©

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

Faculty of Physical Education And Recreation

Edmonton, Alberta

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I dedicate my successful completion of this doctoral program
to my wife Carol, children Calvin, Jacob, and Zachary and to my extended family.
Thank you for your support and patience.

ABSTRACT

The purpose of this study was to compare the physiological adaptations of a combined muscular strength and aerobic endurance training program to strength or aerobic training only on one repetition maximum strength, peak oxygen consumption, the second ventilatory threshold, muscle cross sectional area, body composition, serum creatine kinase, urinary free cortisol, and serum total testosterone in adults with a physical disability. Thirty-seven (13 female, 24 male) volunteers, recruited from The Steadward Center, University of Alberta, participated in a 12 week training program. Participants, aged 18.0 to 51.5 years, with either spinal cord lesion (SCL), cerebral palsy/head injury (CP/HI) or multiple sclerosis (MS) were recruited. Participants were stratified by disability and gender and then randomly assigned to one of the four groups: 1) strength (S) - 10 participants, 2) endurance (E) - 10 participants, 3) strength and endurance (S&E) - 8 participants, and 4) control - 9 participants. The S and E groups trained 3 times per week with a moderately intense, individually prescribed progressive training program. The S&E group trained 5 days per week, alternating daily strength and endurance sessions, except on Fridays when they performed both modes of training. Participants were tested prior to training, at the mid-point, and after completing 12 weeks of training. Significant strength increases were found for the S&E group with no evidence ($\underline{p} \leq .05$) of a diminished response compared to the S group. No significant changes were demonstrated in the participants' peak oxygen consumption or oxygen consumption at ventilatory threshold. Significant gains in the power outputs achieved at ventilatory threshold and peak aerobic efforts were observed in the E and S&E groups. Strength training performed by the S&E group facilitated a significantly greater gain in power output at ventilatory threshold when compared to the E group. No significant changes were demonstrated in muscle hypertrophy measured by diagnostic ultrasound. No significant changes in body composition, serum creatine kinase, sex hormone binding hormone, serum total testosterone, or urinary free cortisol were detected. This study did not demonstrate any compromised adaptations to muscular strength or aerobic endurance as a result of training for both strength and endurance concurrently.

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LIST OF ACRONYMS

ADL	Activities of Daily Living
AT	Anaerobic Threshold
ANOVA	Analysis of Variance
BP	Blood Pressure
bpm	Beats Per Minute
C	Control Group
Cl/e	Control Group (ambulatory)
CP/HI	Cerebral Palsy/Head Injury
Cu/e	Control Group (wheelchair users)
DEXA	Dual Energy X-Ray Absorptiometry
DUS	Diagnostic Ultrasound
E	Endurance Training Group
El/e	Endurance Training Group (ambulatory)
Eu/e	Endurance Training Group (wheelchair users)
HR	Heart Rate
ICC	Intraclass Correlation Coefficient
LE	Lower Extremity
MRI	Magnetic Resonance Imaging
MS	Multiple Sclerosis
MU	Motor Unit

PTI	Person by Treatment Interaction
RHC	Rick Hansen Centre
SCL	Spinal Cord Lesions
S&E	Combined Training Group
S&El/e	Combined Training Group (ambulatory)
S&Eu/e	Combined Training Group (wheelchair users)
S	Strength Training Group
Sl/e	Strength Training Group (ambulatory)
Su/e	Strength Training Group (wheelchair users)
UE	Upper Extremity
VT	Ventilatory Threshold
VT2	Second Ventilatory Threshold
$\dot{V}_E \backslash \dot{V}_{co2}$	Ventilatory Equivalent of Carbon Dioxide
$\dot{V}O_2$	Oxygen Consumption
$\dot{V}O_{2\,max}$	Maximal Oxygen Consumption
$\dot{V}O_{2\,peak}$	Peak Oxygen Consumption
1RM	One Repetition Maximum
8RM	Eight Repetition Maximum

CHAPTER I
INTRODUCTION

In recent years the interest in exercise for people with physical disabilities has increased (Noreau & Shephard, 1995). The physically disabled population has a higher mortality rate and is at higher risk for secondary chronic diseases including cardiac disease and stroke than their able-bodied peers (Dearwater, et al., 1986; Fletcher, Lloyd, Waling, & Fletcher, 1988; Noreau & Shephard, 1995; Pentland, 1993; Pitetti, 1993; Shephard, 1991). The application of the Brockport Physical Fitness Test (Winnick, 1999), UNIQUE Physical Fitness Test (Winnick & Short, 1991), and other fitness testing batteries indicate that many people with physical disabilities demonstrate low fitness levels and sedentary lifestyles. The sedentary nature of the physically disabled population may be attributed to varied physical, psychological, sociological, and societal factors, whether the means of mobility is a wheelchair or independent ambulation (Curtis, Steadward, & Weiss, 1990; Ferrara & Laskin, 1997; Pentland, 1993; Pitetti, 1993; Shephard, 1991). To address this growing problem, education and health professionals are encouraged to promote a life-long commitment to physical activity for people with physical disabilities (Department of Health and Human Services, 1991, Healthy People 2000; Department of Health and Human Services, 2000 Health People 2010).

Growing segments of the physically disabled population participate in recreation, competitive sports, or both. With this increasing level of participation comes an increasing demand for information about sport and disability-specific training programs and exercise prescription (Pitetti, 1993).

The published research which focuses on the physiological adaptations to exercise in the physically disabled population is limited. In general, health professionals rely on the extensive literature available on able-bodied exercise adaptations to guide the rehabilitation and training programs for people with physical disabilities. Dependence on the able-bodied literature is not always applicable to those with physical disabilities. The current training programs that wheelchair marathon athletes follow provide an example of the diverging philosophies for the preparation of marathoners (Liow & Hopkins, 1996). Today's successful wheelchair racers use high-intensity activity specific training programs that have little in common with those of their able-bodied peers (M. Moris, personal communication, May 28, 1995). This example may not represent an isolated case, but rather illustrates a potential theme in the rehabilitation and recreational setting. Given this situation, a critical component to consider is the health professional's ability to appropriately prescribe exercise programs for people with physical disabilities.

Whether a client's goals are health or sport related, aerobic endurance and muscular strength are universal parts of the exercise prescription. However, the current literature, as well as our understanding of how people with physical disabilities adapt to various modes, intensities and progressions of exercise is limited. The typical approach to exercise prescription follows the American

College of Sports Medicine able-bodied guidelines of a combined muscular strength, felxibility, and aerobic endurance program (American College of Sports Medicine, 2000). While this combined approach may be appropriate, Hickson's (1980) introduction of the "interference effect" suggests that a combined strength and endurance exercise program may be flawed.

Hickson (1980) coined the term "interference" to describe the phenomenon of the attenuated muscular strength gains of his combined strength and endurance training group as compared to the strength training only group. Dudley and Fleck (1987) also suggested that when training both fast twitch and slow twitch motor units there is a risk of compromised adaptations of the fast twitch motor units. Improved cardiovascular function (e.g., decreased heart rate and increased stroke volume at any given sub-maximal power output) and improved oxidative capacity in the activated skeletal muscle mass are examples of the physiological adaptations that are typically atributed to aerobic endurance exercise. Muscular strength training results in increased skeletal muscle cross-sectional area, increased motor unit recruitment, and a more synchronized motor unit firing pattern (Kraemer, Deschenes, & Fleck, 1988; Stone, Fleck, Triplett, & Kraemer, 1991). Given that a number of the specific physiological adaptations to muscular strength and aerobic endurance training are inherently different, training for both muscular strength and aerobic endurance simultaneously may be incompatible.

Research with able-bodied subjects has shown that strength gains may be attenuated when muscular strength and aerobic endurance are trained concurrently (Bell, et. al., 1991; Dudley & Djamil, 1985; Esser & White, 1990; Hickson, 1980; Hennessy & Watson, 1994; Hortobágyi, Katch, & Lachance, 1991; Hunter, Demment, & Miller, 1987; Kraemer et al., 1995; Sale, Jacobs, MacDougall, & Garner, 1990). Other studies have suggested that strength training may actually enhance endurance training adaptations (Ferhetich, Kirby, & Alway, 1998; Hickson, Dvorak, Gorostiaga, Kurowski, & Foster, 1988). There have also been a number of studies that have demonstrated neither an attenuation of strength nor an enhancement of endurance (McCarthy, Agre, Graf, Pozniak, & Vailas, 1995; Nelson, Arnall, Loy, Silvester, & Conlee, 1990; Sale, MacDougall, et al., 1990). No published data is currently available pertaining to people with physical disabilities training concurrently for muscular strength and aerobic endurance.

The purpose of this study was to compare the physiological adaptations of a combined muscular strength and aerobic endurance training program to strength or aerobic training only on one repetition maximum strength, peak oxygen consumption, the second ventilatory threshold, muscle cross sectional area, body composition, serum creatine kinase, urinary free cortisol, and serum free testosterone in adults with a physical disability. Specifically, the study examined whether an adaptational incompatibility in training responses occurs in people with physical disabilities when participating in a moderate, progressive, combined strength and endurance training exercise program. The methodology detailed in Chapter III was designed to investigate the following null hypotheses:

Primary

Concurrent muscular strength and aerobic endurance training has no adverse effect on strength training adaptations as compared to muscular strength training alone.

Secondary

1) The mode of mobility has no effect on the rate or magnitude of the adaptations:
   a) to muscular strength training,
   b) to aerobic endurance training,
   c) to concurrent muscular strength and aerobic endurance training.
2) The type of physical disability has no effect on the rate or magnitude of the adaptations:
   a) to muscular strength training,
   b) to aerobic endurance training,
   c) to concurrent muscular strength and aerobic endurance training.

There are some important but unavoidable methodological limitations to this study. These limitations include concerns related to a small sample size, the varied functional abilities of the subjects, and the inclusion of several types of physical disabilities. It is hoped that the results of this study will encourage continued research into the physiological adaptations to aerobic endurance and muscular strength training and the relationship between these two modes of exercise, regardless of the type of population examined. Beyond the scientific merit of this study, the results will contribute to a better understanding of the exercise response in people with physical disabilities and facilitate the development of appropriate fitness and rehabilitation programs.

CHAPTER II
REVIEW OF LITERATURE

Introduction

Since the mid 1980's the literature concerning exercise for special populations has expanded in scope from predominantly the pediatric, geriatric, and diabetic populations to include those with physical disabilities. It has become apparent from this literature that the adaptations to exercise observed in the able-bodied adult population are not necessarily directly applicable to special populations. However, the knowledge and principles about exercise adaptations in the able-bodied population provide a framework for comparison. For the purposes of this review, two disability groups, spinal cord lesions and cerebral palsy/head injury, (SCL and CP/HI) have been used to represent those individuals with physical disabilities. The SCL category includes people with traumatic spinal cord injuries, polio, or spina bifida. The CP/HI category includes people with either congenital or acquired cerebral palsy, traumatic brain injuries, or any other non-progressive brain injury (e.g., cerebral vascular accidents).

Upper Versus Lower Extremity Exercise

Able-bodied Individuals

Some people with physical disabilities are primarily ambulatory and others are primarily wheelchair users. Therefore, an understanding of the fundamental differences between exercise performed by the upper extremities (UE) versus the lower extremities (LE) in the able-bodied population is required before examining any potential disability specific characteristics.

Table 2-1 provides an overview of the distinguishing characteristics of the UE compared to the LE. In humans the UE contains less skeletal muscle mass than does the LE (Marieb, 1995). Myological studies show that the human UE has an equal or slightly greater proportion of Type II to Type I muscle fibers compared with the LE. The LE has a preponderance of Type I muscle fibers (Johnson, Polgar, Weightman, & Appleton, 1973; Lamb, 1984). The combination of functional muscle mass and fiber type composition results in the UE tending to be more fatigable and having a lower capacity for force production in both

Table 2-1

Summary of Upper Versus Lower Extremity Physiological Characteristics

Characteristic	Upper Extremity	Lower Extremity
Fatigability	more	less
Force production absolute & relative	less	more
Predominant fibre type composition	fast	slow
General peripheral adaptability	less	more
Overall skeletal muscle mass	less	more

Note. Adapted from "Cardiovascular, Respiratory and Metabolic Responses to Upper Body Exercise" by D. R. Pendergast, 1989, Medicine and Science in Sports and Exercise, 21(5), pp. S121-S125; and "Introduction: upper body exercise: physiology and practical considerations," by M. N. Sawka, 1989, Medicine and Science in Sports and Exercise, 21(5), pp. S119-S120.

absolute and relative terms. The net effect of the characteristics noted in Table 2-1 is the UE has a reduced ability to adapt when presented with either strength or aerobic endurance stimuli (Pendergast, 1989; Sawka, 1989).

Many health care professions may make the assumption that there are no fundamental differences in the training adaptations observed between the UE and the LE. This is probably true for peripheral adaptations such as the oxygen/nutrient delivery and waste removal pathways, the morphological makeup (except fiber type), and motor unit recruitment patterns (Pendergast, 1989; Sawka, 1986). Many peripheral adaptations to exercise are similar between the UE and LE. A few examples include:

1) Muscular Strength Training
    - absolute and/or relative decrease in mitochondrial content
    - possible increased bone mineral content
    - skeletal muscle and connective tissue hypertrophy
    - increased number of motor units firing synchronously
2) Aerobic Endurance Training
    - capillary density increases
    - coordination/cycling of motor unit firing
    - increased glycogen storage and oxidative enzyme availability
    - mitochondrial proliferation (volume and density)
    - selective Type I muscle fibre hypertrophy

Table 2-2 presents a more detailed outline of both the peripheral and central

Table 2-2

Upper Versus Lower Extremity Physiological Adaptations to Long Term Exercise

Mode Appropriate Adaptations	Upper Extremity	Lower Extremity
Peripheral Adaptations		
Absolute & Relative Strength	⇑	**⇑**
Aerobic Capacity	⇑	**⇑**
Anaerobic Power	⇑	**⇑**
Motor Unit Efficacy	⇑	**⇑**
Muscle Fibre Hypertrophy	⇑	**⇑**
Muscular Endurance	⇑	**⇑**
Regional Blood Flow	⇑	**⇑**
Substrate/Enzyme Efficacy & Storage	⇑	**⇑**
Central Adaptations		
Blood Volume	⇒	**⇑**
Blood Pressure (rest & sub-max)[a]	⇓	**⇓**
Cardiac output	⇒	**⇑**
HDL : LDL Cholesterol Ratio[b]	⇒	**⇑**
Heart Rate (rest & sub-max)	⇓	**⇓**
Peak Oxygen Consumption	⇑	**⇑**
Oxygen Delivery System	⇒	**⇑**
Stroke Volume	⇒	**⇑**
Ventilatory Threshold	⇑	**⇑**

Note. The arrows denote the relative magnitude and direction of the adaptations. The ⇒ refers to no change in status. [a] Both systolic and diastolic. [b] High density lipoprotein: Low density lipoprotein ratio. Adapted from "Physiology of Upper Body Exercise" by M. N. Sawka, 1986, In K. B. Pandolf (Ed.), Exercise and Sport Sciences Reviews (Vol. 14, pp. 175-211). New York: Macmillian Publishing Company. & "Introduction: Upper body exercise", by M. N. Sawka, 1989, Medicine and Science in Sports and Exercise, 21(5), pp. S119-S120.

adaptations observed with long term UE and LE exercise programs. The able-bodied exercise physiology literature (as demonstrated in Table 2-2) has shown that despite varying potentials for adaptation, both the UE and the LE are able to adapt peripherally. However, the ability of UE exercise to facilitate central adaptations is limited. Table 2-2 suggests that the types of central adaptations to aerobic endurance exercise are extremity specific. This limited ability of UE exercise to elicit central adaptations causes concern for health professionals involved in providing exercise prescriptions for the wheelchair user (Keyser, Mor, & Andres, 1989; Langbein & Maki, 1995; Pendergast, 1989; Sawka, 1989; Van Loan, McCluer, Loftin, & Boileau, 1987). The inability to demonstrate centrally driven adaptations to UE exercise raises questions about applying the basic able-bodied exercise prescription model of using moderate levels of LE exercise to control blood pressure, decrease the resting heart rate, and to mediate the ratio of high to low density lipoprotein (McArdle, Katch, & Katch, 1996, pp. 646; Miles, Cox, & Bomze, 1989). In other words, moderate levels of UE exercise may not produce the same central adaptations as moderate levels of LE exercise.

Table 2-3 presents a comparison of the physiological response to exercise when performed by either the UEs or the LEs. To summarize, at any given sub-maximal workload, UE exercise results in a greater physiological response as compared to LE exercise. This elevated response is due to the UE's greater workload to muscle mass ratio. During sub-maximal workrates the

Table 2-3

Summary of the Physiological Responses of Upper Versus Lower Extremity Exercise During Sub-Maximal and Maximal Aerobic Exercise

	Sub-Maximal Exercise[a]		Maximal Exercise	
Adaptation	UE	LE	UE	LE
Power output	✓	✓	✓	✓✓
Blood pressure (systolic)	✓✓	✓	✓	✓
Blood pressure (diastolic)	✓✓	✓	✓✓	✓
Blood volume	✓	✓	✓	✓✓
Cardiac output	✓	✓	✓	✓✓
HR	✓✓	✓	✓	✓✓
Myocardial contractility	✓	✓	✓	✓
Myocardial $\dot{V}O_2$	✓✓	✓	✓	✓
Total $\dot{V}O_2$	✓✓	✓	✓	✓✓
Stroke volume	✓	✓✓	✓	✓✓
Total peripheral resistance	✓✓	✓	✓✓	✓
Venous (pooling)	✓✓	✓	✓✓	✓
Venous (return)	✓	✓✓	✓	✓✓

Note. [a] Sub-maximal exercise is compared at equivalent power outputs. [b] ✓✓ The greater value or measure of UE versus LE exercise. Adapted from "Cardiovascular Responses to Upper Body Exercise in Normals and Cardiac Patients" by D. S. Miles, M. H. Cox, & J. P. Bomze, 1989, Medicine and Science in Sports and Exercise, 21(5), pp. S126-S131; "Physiology of Upper Body Exercise" by M. N. Sawka, 1986, In K. B. Pandolf (Ed.), Exercise and Sport Sciences Reviews (Vol. 14, pp.175-211). New York: Macmillian Publishing Company; and "Cardiovascular, Respiratory and Metabolic Responses to Upper Body Exercise" by D. R. Pendergast, 1989, Medicine and Science in Sports and Exercise, 21(5), pp. S121-S125.

response of cardiac output is similar for UE and LE exercise (Sawka, 1986). The lower stroke volume observed with sub-maximal UE exercise is due to an increase in UE peripheral resistance and venous pooling in the non-exercising LE and abdominal cavity. The UEs have a smaller vascular cross-sectional area as compared to the LEs. The increased UE peripheral resistance is a result of a cardiac output that is similar between the UE and LE being pushed through a smaller vascular bed (Sawka, 1986). Therefore, to supply the required blood flow to the working muscles there is an increase in heart rate (HR) to provide the necessary cardiac output. The greater relative percentage of maximal oxygen consumption ($\dot{V}O_{2\,max}$) observed with sub-maximal UE exercise at the same power output is theorized to be due to the inefficiency of UE work (McArdle et al., 1996). This includes the "isometric work" involved in the hand grip and the activity of the abdominal, back extensor and shoulder muscle complexes that provide trunk stability, balance, and posture. In addition, when performing arm crank ergometry the forces are in a predominantly horizontal plane which does not allow for the gravity assistance provided during the down stroke in cycle ergometry (G. J. Bell, personal communication, August 12, 1997). Even people who are well trained and skilled in UE exercise show significantly less calculated mechanical efficiency when doing UE work compared with LE work. This increase in work results in an elevation of intramuscular pressures combined with an increased UE peripheral resistance to blood flow that produces the rise in diastolic blood pressure (Bhambhani, Eriksson, & Gomes, 1991; Glaser, 1989;

Hopman, Oeseburg, & Binkhorst, 1992; Keyser et al., 1989; Lin, Lai, Kao, & Lien, 1993; Sawka, 1989).

Comparisons of the maximal efforts for UE versus LE exercise in the able-bodied population have demonstrated significant differences. The absolute force produced by the LE is 25% to 35% greater than that produced by the UE (Glaser, 1989). Across disabilities, the research has consistently documented that both the maximal LE treadmill exercise and the age predicted maximum HR calculations result in a maximum HR that is on average ten bpm higher than what is observed with maximal UE arm ergometry (Bhambhani et al., 1991; Connor, 1991; Miles et al., 1989; Pendergast, 1989; Reybrouck, Heigenhauser, & Faulkner, 1975; Sawka, 1989; Swensen & Howley, 1993; Williams, Cottrell, Powers, & McKnight, 1983). Studies of people with low lesion level paraplegia performing maximal wheelchair exercise, have shown that their maximal heart rates were 20 bpm lower than their theoretical age predicted HR maximum (Connor, 1991). This diminished maximal heart rate response is dependent on the exact level and severity of the lesion. People with quadriplegia are limited to a maximal HR of approximately 120 bpm due to the loss of sympathetic regulation (Figoni, 1993, 1997; Ready, 1984). Fernandez, Pitetti, and Betzen (1990) reported that the peak HR achieved with treadmill running compared to arm crank ergometry was significantly greater in untrained participants with CP. They found that arm crank ergometry produced maximal heart rates 25 to 27 bpm lower than rates produced on the treadmill by their male and female participants respectively, versus the common 10 bpm rule of thumb. The stroke volume and cardiac output resulting from maximal LE work were 30 to 40% greater, and $\dot{V}O_{2\,max}$ was from 20% to 35% greater, compared to a maximal UE effort (Connor, 1991; Miles et al., 1989; Pendergast, 1989; Reybrouck et al., 1975; Sawka, 1989).

The maximal LE exercise performance appears to be limited by a combination of both peripheral and central type phenomena, whereas it appears that the limitations to maximal exercise for UE exercise are solely in the peripheral domain (Gollnick, 1982; McArdle et al., 1996, p 307-308). This has also been demonstrated in wheelchair athletes where peripheral type adaptations are the limiting factors for peak performance (Glaser, 1989). The severity of the physical disability and the resulting loss in exercise efficiency may heighten the magnitude of this phenomenon.

Individuals with Physical Disabilities

A large proportion of research dealing with UE exercise and people with physical disabilities has been focused on those with SCL. Sawka, Glaser, Wilde, and von Luhrte (1980) studied a group with low lesion level paraplegia and matched able-bodied (age, activity, and gender) controls. They found no significant differences in the response of HR, cardiac output, stroke volume, or arteriovenous oxygen difference to sub-maximal and maximal exercise using an arm crank ergometer. Van Loan et al. (1987) using able-bodied controls, recruited participants with a range in lesion levels that included people with paraplegia (T4 to L3) and quadriplegia (C5 to C8). They found significant differences in the peak oxygen consumption ($\dot{V}O_{2\,peak}$) among all three groups. The greatest $\dot{V}O_{2\,peak}$ values were achieved by the able-bodied participants, followed by participants with paraplegia and then quadriplegia. Interestingly, the $\dot{V}O_{2\,peak}$ was closely related to lesion level although the within group variance was large. This study found that the stroke volume and cardiac output attained by participants with paraplegia and quadriplegia were significantly less than that of the able-bodied controls. Again, the measured stroke volume and cardiac output appeared to be related to the individual's lesion level. This seems to contradict Sawka et al.'s (1980) findings. However, the authors only observed the responses of low lesion level participants.

Van Loan et al. (1987) observed that people with quadriplegia and high lesion level paraplegia demonstrated significantly lower maximal heart rates. This lowered maximal HR can be explained by their impaired or absent sympathetic drive, decreased available active muscle mass, and generally lowered metabolic rates. Connor (1991) reported a diminished HR response in sedentary SCL wheelchair users at sub-maximal and maximal workloads compared to matched able-bodied controls. This phenomenon was also reported when both groups were athletically trained.

The decreased stroke volume observed in the participants with quadriplegia and or high lesion level paraplegia has been related to a lowered cardiac pre-load (Figoni, 1997). The diminished cardiac pre-load results from lower extremity venous blood pooling and impaired abdominal tone. In other words there is an inadequate LE muscle pump. This inadequate muscle pump may be the contributing factor to a lowered cardiac pre-load for individuals with an acute SCL, however this may not be the mechanism after the acute injury period (Hopman, Monroe, Dueck, Phillips, & Skinner, 1998). Hopman et al. (1998) point out that in individuals with a chronic SCL the venous capacitance is reduced thus limiting the potential contribution of venous pooling on the observed decreased cardiac pre-load. Able-bodied individuals maintain their cardiac pre-load by activating their trunk and LE musculature to reduce blood pooling. This muscle activation is also functional because it is used for stabilization, balance, and to help with UE force production as the power output reached maximal levels. Participants with low lesion level paraplegia were also able to take advantage of any unaffected LE and trunk musculature. Connor (1991) suggests, in her review of the literature, that the lowered stroke volumes found in the wheelchair users as compared to the able-bodied during arm ergometry may be attributed to an increased resistance to peripheral blood flow in the hypertrophied upper body musculature of the wheelchair user. Van Loan et al. (1987) also found no significant differences in the arteriovenous oxygen difference observed between participants with paraplegia and participants with quadriplegia. From this finding, the authors deduced that regional blood flow and oxygen extraction was within normal limits. This provides further evidence that

UE exercise is limited by peripherally adaptive factors, not centrally adaptive factors.

The relationship between SCL lesion level and efficiency during steady state exercise has also been examined. Activities of daily living energy expenditure, respiratory function and exercise tachycardia are influenced by the lesion level (Drory, Ohry, Brooks, Dolphin, & Kellermann, 1990). Yamasaki, Irizawa, Ishii, and Komura (1993) used arm ergometry to examine the lesion level influence on the power output by participants with high (T3 to T8) and low (T10 to L1) lesion levels compared with able-bodied controls. At power outputs of 0 and 30 watts there was no significant differences between groups in mechanical efficiency. However, the researchers observed a trend toward higher efficiency with a lower lesion level as compared to those with high level lesions. This study showed that the able-bodied controls presented a lower overall efficiency than the participants with low lesion level paraplegia. This result may have been because of the novelty of the exercise for the able-bodied group. Yamasaki et al. (1993) also reported a significantly higher ventilation (L/min) and oxygen consumption ($\dot{V}O_2$) for people with high lesion level paraplegia at the 30 watt workload. This may be explained by a more pronounced impairment of the inspiratory muscles and therefore increased respiratory energy expenditure for the high lesion level participants. The authors suggest that these participants could also present with a diminished tidal volume which would explain the increased respiration rates observed with moderate exercise. However, in this study the participants were only exposed to very low workloads and increased respiration rates were not observed.

As the level of the spinal cord lesion rises the magnitude and types of impairments are intensified. For people with quadriplegia a rise in lesion level results in a diminished quantity of functional skeletal muscle mass. Though the diaphragm is spared unless the lesion level reaches C5 through C3, there is still a substantial decrease in respiratory potential due to the loss of the thoracic muscles of respiration (Birk, 1997; Figoni, 1997; Ready, 1984; Somers, 1992, p. 28). This situation is further complicated by the varying degrees of UE innervation and the corresponding ability to perform efficient, functional movements. The disruption of sympathetic outflow results in the loss of effective HR control (Figoni, 1993, 1997; Somers, 1992). Loss of vasomotor control and a sweating response below the level of the lesion has also been observed in people with SCL. As the level of the spinal cord lesion rises there is a heightened concern over the individual's ability to thermoregulate (Figoni, 1997). The inability to effectively redistribute blood flow not only effects thermoregulation but also impacts negatively on the venous pooling in the LE and abdomen during exercise (DiCarlo, 1988; Figoni, 1993, 1997; Pentland, 1993; Somers, 1992, p. 93)

Clinically, there are fundamental differences in how UE exercise places demands on clients as compared with LE activity. The implications of these differences must be considered when prescribing an exercise program. There is strong evidence that the level of a spinal cord lesion significantly affects the responses and adaptations to UE exercise. There are clear differences between the two ends of the spectrum; people with low level lesion paraplegia and people with quadriplegia. The unique physiological characteristics of people with SCL may impede or confound the response to UE and/or LE exercise compared to matched able-bodied peers. Finally, given that people with SCL exhibit variations in their physiological responses to exercise when compared with the able-bodied, the same may be true for other chronic diseases and disabilities.

Physiological Adaptations to Aerobic Endurance and Muscular Strength Training

The objective of this section is to demonstrate that the literature supports the suggestion that people with SCL and CP/HI will respond to both muscular strength and endurance training programs.

Spinal Cord Lesions and Aerobic Endurance Training: Maximal Oxygen Consumption

Hjeltnes (1984) performed repeated cardiovascular evaluations on a series of patients with SCL during their initial rehabilitation. The participants performed eight weeks of daily arm ergometry followed by eight weeks of functional activities. Hjeltnes (1984) reported significant increases in $\dot{V}O_{2\,max}$ after the 16 weeks of training. The most dramatic changes occurred during the initial arm cranking training period. The author assumed that arm cranking was a superior form of exercise as compared to functional activities such as wheeling. However, the participants were initially at such low levels of fitness that during the second eight-week period an equivalent amount of change was unlikely even if the patients had continued an arm cranking program. An important follow-up to this study would be to include a second experimental group which performed the functional activities during the first eight weeks followed by arm cranking for the remainder of the study and/or a control group that performed functional activity only. This study showed that even functional training resulted in significant improvements in aerobic capacity.

Sedlock, Fitzgerald, Knowlton, and Schneider (1983) and Sedlock, Knowlton, and Fitzgerald (1988) reported significant training effects in people with paraplegia following five weeks of three times per week arm crank ergometry at 70% of maximum HR. At any given sub-maximal workload the intensity specific blood lactate decreased and the stroke volume increased without a corresponding change in the cardiac output. The participants' resting HR also decreased.

An earlier study using wheelchair athletes was completed by Miles et al. (1982). These athletes had unexpectedly low fitness levels at the initial evaluation. The athletes performed interval training workouts on wheelchair ergometers three times per week for six weeks. The $\dot{V}O_{2\,peak}$ increased significantly. Total ventilation also significantly increased, this may have resulted from an increase in respiratory frequency rather than an increased tidal volume. There was improvement in the muscular development and efficiency of the respiratory musculature. Millar and Ward (1983) also reported significant increases in $\dot{V}O_{2\,max}$ while monitoring an intensive wheelchair track training program. The authors documented mean changes in $\dot{V}O_{2\,max}$ from 45.2 ml/kg/min to 54.4 ml/kg/min. These athletes, even though they were fit before the onset of the training program, demonstrated substantial improvements.

Davis, Plyley, and Shephard (1991) assessed the value of four different training regimens using four groups of previously inactive men with paraplegia. The three training groups were: 1) 40 min of arm cranking at 70% of $\dot{V}O_{2\,max}$; 2) 40 min at 50% of $\dot{V}O_{2\,max}$; and 3) 20 min at 50% of $\dot{V}O_{2\,max}$. All groups trained three times per week for 24 weeks. After 16 weeks, only 15 of the initial 24 participants remained in the study. Thus, the only complete set of results was from the initial eight weeks of training and these results were inconclusive. The participants remaining after eight weeks showed significant decreases in HR at any given sub-maximal workload. Significant $\dot{V}O_{2\,max}$ improvements were documented for all groups.

For people with quadriplegia the limited availability of innervated skeletal muscle mass places restrictions on functional activities. Therefore, they tend to live a sedentary lifestyle (Figoni, 1993). Because of their small amount of trainable muscle mass it is unlikely that the central oxygen delivery system would be stressed when they perform maximal aerobic exercise. This need not preclude people with quadriplegia from improving their fitness functional status (Figoni, 1993, 1997; Pentland, 1993). DiCarlo (1988) evaluated eight previously sedentary men with quadriplegia during an eight-week arm ergometry training program. The participants trained three times per week at 50-60% of their predicted maximal HR reserve (125 -135 bpm). The author manipulated either the cadence or the duration and progressed from a 10 min workout performed at 50 rpm to a 30 min workout performed at 60 rpm during the course of the study. The HR at any given sub-maximal workload was significantly reduced. The $\dot{V}O_{2\,max}$ improved from 12.1 ± 0.54 ml/kg/min to 23.5 ± 3.1 ml/kg/min, a 99% increase. Finally, there was a 78% increase in the wheeling distance covered in 12 minutes (1.18 ± 0.1 km to 2.1 ± 0.14 km). A large window of adaptability is evident, which may be partially explained by the initial low level of fitness. However, to put this into perspective, a $\dot{V}O_{2\,max}$ of 23.8 ± 2.0 ml/kg/min is typical of the untrained sedentary high lesion level (T4 to T6) paraplegic (Gass, Harvey, & Gass, 1995).

Hopman, Dallmeijer, Snoek, and van der Woude (1996) followed a group of 15 individuals with quadriplegia who played Quad Rugby and 6 individuals with quadriplegia who were sedentary controls (C4 to C8 spinal cord lesions) over a 6 month period. The rugby players were separated into two groups: 1) athletes who had played at least two times per week for two years and 2) athletes who started to train regularly at the onset of the study. Both sub-maximal and maximal arm cranking protocols were used in order to assess the participants' initial level of physical fitness and to study the subsequent changes over the six month period. The participants trained an average of 1.5 hours per week with HR intensities above 60% of their HR reserve for approximately 35% of the workout time. Hopman et al. (1996) reported no significant improvements in either group's physical fitness status over the six month period. The authors suggested that this was due to the low intensity and the frequency of the training. However, they noted that several of the individuals, particularly those from the untrained group, demonstrated large improvements.

Ready (1984) recruited six athletes with quadriplegia to evaluate their responses to sub-maximal and maximal aerobic exercise. The methods for testing and the responses to the exercise stimuli were similar to those discussed above. Ready (1984) concluded that people with quadriplegia required an extended time course to observe significant improvements in their cardiopulmonary fitness.

Ventilatory Threshold

Anaerobic threshold (AT) measurement is often used for assessing cardiovascular fitness and prescribing endurance exercise (Cheng, et al., 1992). There are two distinctly different metabolic thresholds described in the literature and both are related to the accumulation of blood lactate (Bhambhani & Singh, 1985). Blood lactate levels are obtained via direct sampling of venous blood. During the initial workloads of a graded exercise test the energy requirements are satisfied predominantly by the aerobic metabolism. At some given workload the exercising muscles' demands for energy will exceed what is available aerobically. The aerobic systems deficiencies will be made up for by the anaerobic energy system, which will result in an increased concentration of lactic acid in the blood. This first threshold, where lactic acid begins to accumulate in the blood, has been defined most commonly as the aerobic threshold. As the graded exercise test proceeds the demands on the anaerobic system is increased. With rising anaerobic demands the amount of lactic acid produced that must be buffered by the sodium bicarbonate buffering system is increased. At some workload during the graded exercise test the sodium bicarbonate buffering system is unable to buffer the lactic acid production and there is an abrupt increase in the blood lactate concentration. This increased blood lactate concentration causes a decrease in pH which results in an increased minute ventilation ($\dot{V}_E$). This point is considered to be the second metabolic threshold or more typically the AT. This second threshold has also been termed the threshold of decompensated metabolic acidosis (Bhambhani & Singh, 1985; Reinhard, Muller, & Schmulling, 1979).

Ventilatory threshold (VT) determinations are the most common non-invasive method for estimating the onset of blood lactate accumulation during a graded exercise tests (Kara, Gokbel, & Bediz, 1999). This non-invasive method requires continuous collection of expired gases during an incremental exercise test to volitional exhaustion. Associated with the first metabolic threshold, ventilatory threshold one (VT1) occurs at the workload where the ventilation volume/oxygen consumption ratio ($\dot{V}_E/\dot{V}O_2$) and the fraction of oxygen in the expired gas (F_EO_2) reach minimum values. The ventilatory threshold two (VT2) associated with AT occurs at the workload where the ventilation volume/voiume of carbon dioxide produced ($\dot{V}_E/\dot{V}CO_2$) reaches a minimum and the fraction of carbon dioxide in the expired gas (F_ECO_2) reaches a maximum. The reasoning behind the designations of VT1 and VT2 is that the $\dot{V}_E/\dot{V}O_2$ ratio consistently reaches a minimum before the $\dot{V}_E/\dot{V}CO_2$ ratio does (Bhambhani & Singh, 1985). This delay is predominantly due to the ability of the blood to store large quantities of CO_2 (Plowman and Smith, 1997).

Carbon dioxide levels in the blood can have significant effects on respiration. An increased concentration of CO_2 in the blood provides a potent stimulus which will facilitate an increase in $\dot{V}_E$ (Jones and Ehrsam, 1982). During graded exercise there is an incremental rise in $\dot{V}_E$ until the power output demand exceeds the bodies ability to balance the turnover rate of lactate production and removal fails (Plowman and Smith, 1997). The resulting breakpoints, VT1 and VT2, represent the body's attempts to cope with a changing metabolic environment during graded exercise. The accumulation of lactic acid in the blood and its subsequent disassociation into lactate and hydrogen ions results in the a lowering of the blood pH. The body responds by using chemical buffers such as sodium bicarbonate to bind with these hydrogen ions and create carbonic acid, which then further breaks down into water and CO_2. As mentioned above increasing concentrations of CO_2 in the blood cause an increased ventilation, which is a simple and effective method for removing CO_2 from the body (Jones and Ehrsam, 1982). Therefore, by evaluating the ventilatory response of an individual during graded exercise the researcher can identify, noninvasively, VT1 and VT2 which occur coincidently with LT1 and LT2 (Plowman and Smith, 1997).

Although the two VT measurements are related to the two metabolic thresholds they are not directly regulated by lactate accumulation in the blood. Many studies have been performed to examine the relationship between VT2 and AT. Some researchers have reported that the two measurements are identical, but more often differences have been found (Robergs & Roberts, 1997). In fact Gladden et al. (1985) reported differences in the exercise intensity at which VT2 and AT were reached was 8% of $\dot{V}O_{2\,max}$ or more. Alterations in carbohydrate nutritional status, enzyme deficiency diseases (McArdle syndrome), methodological error, and specifics of exercise training are some of the potential factors which are responsible for these variations of these two measures. Therefore, Bhambhani and Singh (1985) suggest that the metabolic terms of aerobic and anaerobic threshold should not be used when using non-invasive methodologies.

Spinal Cord Lesions and Aerobic Endurance Training: Ventilatory Threshold

Flandrois et al. (1986) investigated the aerobic capacity of nine subjects with paraplegia (lesion levels T4 to L2) as compared to nine voluntary, able-bodied subjects. At LT (the second threshold - an abrupt increase in blood lactate concentration) there was no significant differences in power output or $\dot{V}O_2$ the two groups. The $\dot{V}O_{2\,max}$ achieved was significantly greater for the able-bodies group and was directly related to the level of injury for those with paraplegia. Given that LT is related to the proportion of muscle mass involved with an activity, it is not surprising that the LT expressed as a percentage of $\dot{V}O_{2\,max}$ was greater for the subjects with paraplegia as compared to the able-bodied subjects.

Lin, Lai, Kao, and Lien (1993) sampled a much larger group of individuals with paraplegia (39) to investigate the aerobic capacity of individuals with paraplegia as compared to a matched group (age, height, and weight) of able-bodied subjects. Lin et al. (1993) used expired gas collection and evaluation as a non-invasive method to determine AT. The definition of AT used in this study was the power output or $\dot{V}O_2$ were the accumulation of blood lactate suggests the onset of anaerobic metabolism. Using arm ergometry, these authors findings agreed with Flandrois et al. (1986) in that those with paraplegia demonstrate both sub-maximal and maximal aerobic capacity as compared to the able-bodied group.

Rotstein et al. (1994) evaluated aerobic capacity and AT in eight wheelchair basketball athletes using their own chairs on a motor driven treadmill and using arm ergometry. This study used the fixed level of blood lactate at 4 mmol/L as the determination of AT. The authors reported that given their subjects were all members of the Israeli national men's wheelchair basketball team, the aerobic capacities were lower than expected. Due to the poor correlations of ventilatory measures between the arm ergometer and treadmill sessions ($r < 0.6$) Rotstein et al. (1994) suggest that the ergometer type used in testing may have played a role in these lower that expected values.

Coutts and McKenzie (1995) recruited 30 male wheelchair athletes, 8 with quadriplegia, 18 with paraplegia, and 4 with bilateral above knee amputations. The authors were primarily concerned with VT. They suggest that VT could be used as an index of sub-maximal aerobic capacity, lesion level classification, and sport performance specificity. Coutts and McKenzie (1995) found that the VT determinations were significantly different between participants with paraplegia (1.36 L/min to 1.89 L/min) and quadriplegia (0.69 L/min to 0.95 L/min) and among the three sport categories of track (1.95 L/min), basketball (1.62 L/min), and other (1.26 L/min). The VT results, expressed as a percentage of $\dot{V}O_{2\,max}$, followed a similar pattern between groups without a sport specific differentiation. Coutts and McKenzie (1995) also reported that there was a significant difference between the $\dot{V}O_{2\,max}$ attained by participants with paraplegia and those with quadriplegia. Participants with amputations did not perform significantly different from participants with paraplegia. In addition, they reported that participants with paraplegia and amputations who participated in track (2.80 L/min) presented significantly greater $\dot{V}O_{2\,max}$ values as compared to participants who played basketball (2.41 L/min).

Bhambhani et al. (1995) evaluated the VT in eight untrained and eight endurance-trained men with quadriplegia. The investigators used wheelchair rollers to allow the subjects to perform a simulated wheelchair activity in their own everyday chair. Bhambhani et al. (1995) found no significant difference between the untrained and trained groups when VT was examined as a percentage of $\dot{V}O_{2\,max}$. However, the trained group demonstrated significantly greater relative $\dot{V}O_2$ at VT as compared to the untrained group. Therefore, the authors suggest that endurance training will enhance VT in persons with quadriplegia, but not when expressed as a percentage of $\dot{V}O_{2\,max}$.

A common concern in the evaluation of the adaptations to aerobic exercise is ensuring that the cardiovascular performance measurements are reliable. Bhambhani, Eriksson, and Steadward (1991) evaluated two participants with low lesion level paraplegia (T10/11 and T11/12) and five participants with quadriplegia (C6/7). A test-retest methodology was followed on friction-free wheelchair rollers. High correlations between tests were observed among the six measured peak values that included: $\dot{V}O_2$ ($r = 0.98$), HR ($r = 0.97$), and ventilation rate ($r = 0.96$). These data suggest that wheelchair ergometry provides a reliable method of estimating cardiovascular performance.

Gass et al. (1995) compared the response between wheelchair and arm ergometers. This study used nine untrained men with T4 to T6 complete paraplegia. Gass et al. (1995) reported that there were no significant test-retest differences between the two modes of exercise for the measured peak ventilation rate, absolute and relative $\dot{V}O_2$, and HR.

It appears from these two examples (Bhambhani et al., 1991 and Gass et al., 1995) that even with relatively small sample sizes the use of standardized testing protocols will result in repeatable objective measurements of aerobic capability.

Cerebral Palsy/Head Injury and Aerobic Endurance Training: Maximal Oxygen Consumption and Ventilatory Threshold

When compared to the SCL literature available, there exists only a small body of published literature regarding people with CP/HI and their adaptations to exercise (Parker, Carriere, Hebestreit, Salsberg, & Bar-Or, 1993). As with the SCL population, the CP/HI population presents with a large range of lesions and therefore, the resulting functional abilities will be individualized. The commonality is that these individuals have all survived a congenital or acquired upper motor neuron lesion. Unique to this population are the potential influences and interplay of spasticity, incoordination, ataxia, and/or athetosis. Additional influences are the compensatory or abnormal movement patterns that develop to maximize an individual's function. None of these factors has been investigated with regard to how they effect an individual's response to UE or LE exercise (DePauw & Gavron, 1995; Ferrara & Laskin, 1997; Palmer-McLean & Wilberger, 1997; Parker et al., 1993)

A large percentage of individuals with CP/HI have concomitant cognitive deficits, and these deficits could influence how this population responds to exercise (DePauw & Gavron, 1995). However, Winnick and Short (1991) found no relationship between cognitive function and the level of physical fitness. This descriptive study incorporated the use of a physical fitness battery with 203 adolescents with CP who were classified as non to mildly retarded. These young people demonstrated fitness and performance levels that were significantly lower than their age-matched able-bodied peers. Winnick and Short (1991) also expressed a concern that any effect of impaired cognitive function may have on physical fitness was obscured by the impact of their physical disability.

Dresen, de Groot, Menor, and Bouman (1985) recruited eleven children (5 of which were controls), 8 to 14 years of age, to participate in a 10 week physical exercise program. Most of the children presented with either spastic hemiplegia or spastic diplegia. All training sessions were built into the children's` regular school day. The activities consisted of three sessions per week, each session involving one of the following activities: swimming, games, or judo. The goal was to maintain the child's HR above 160 bpm for as long as possible during each session. Each of the five controls continued to participate in their regular physical education programs. Dresen et al. (1985) reported no significant changes in the predicted $\dot{V}O_{2\,max}$. However, there was a significant decrease in the $\dot{V}O_2$ for any given sub-maximal workload, suggesting an increase in mechanical efficiency. The authors discussed whether the HR target was high enough to stimulate a more significant cardiovascular response. They concluded that the duration of the training period was too short. On average, of the 120 minutes per week devoted to training, the desired 160 bpm HR threshold was achieved for only 61 min per week (19.1 ± 6.0 min for games, 15.0 ± 7.6 min for swimming, and 27.0 ± 18.0 min for judo).

Wolman, Cornall, Fulcher, and Greenwood (1994) conducted a 6 to 11 week training program using 6 adult patients with brain injuries. The purpose of the study was to examine the feasibility and value of an aerobic exercise program in the rehabilitation of adults with brain injuries. They were concerned about the patient compliance and if it were "possible to get any measurable aerobic response" (Wolman et al., 1994, p. 254). All patients were ambulatory and demonstrated mild to moderate forms of hemiparesis or paraparesis. Some patients also exhibited ataxia and mild levels of cognitive impairments. These individuals trained on a cycle ergometer three times per week for 30 minutes at 60% to 80% of their age predicted maximum HR. They used a simple timed-incremental exercise test where only heart rates and elapsed time were recorded. Overall, there was a significant increase in the duration of the incremental test from 8.0 min to 12.5 min. The HR at any given sub-maximal workload was decreased. In addition, the mean training power output increased from 52 to 95 watts. This study clearly showed the potential for improvement in this population. The efficacy of this program would have been augmented by showing the transfer of improved physical fitness to enhanced function. Unfortunately, the authors did not incorporate functional testing into their methodology.

The ability of a person with CP/HI to work at a sub-maximal exercise level for a prolonged period of time should be a basic functional outcome of any aerobic exercise program. Fernandez and Pitetti (1993) reported that the literature demonstrated that general manual labour was performed at approximately 33% to 40% of the able-bodied individuals` physical work capacity when the individual is allowed to set their own pace. The general fitness levels found in individuals with CP/HI tends to be low (Winnick & Short, 1991). In order to keep up with their able-bodied peers these low fit individuals would have to work at considerably higher percentage of their physical work capacity. In an attempt to keep up the expected working pace the individual with CP/HI may fatigue before the end of an eight-hour workday. Previously, Lundberg (1976) reported a 50% reduction in physical work capacity at 170 bpm among five adult men with CP/HI compared to age-matched controls. To evaluate the effect of a physical training program on the ability to perform seven simulated work tasks, Fernandez and Pitetti (1993) recruited seven ambulatory adults with moderate to severe spastic CP. The participants exercised on a Schwinn Air-Dyne ergometer twice a week for eight weeks. They exercised for a total of 30 minutes per session at intensities that stimulated heart rates of 40% to 70% of the physcial work capacity. The time spent at a given intensity was increased over the eight-week training period. These participants significantly improved their physical work capacity and their performances of the seven simulated work tasks. Fernandez and Pitetti (1993) concluded that individuals with CP/HI could benefit from even very basic physical training programs and these benefits will carry over to functional activities.

The validity and reliability of testing $\dot{V}O_{2\,max}$ on CP/HI wheelchair athletes was reported by Bhambhani, Holland, and Steadward (1992). They recruited a sample of six adult male athletes. Four were classified as CP4 and two as CP3 (see Appendix - 3). Each participant performed two graded protocols on the wheelchair ergometer (their own wheelchair on friction free rollers) and four of the participants were also able to complete two tests on a cycle ergometer. Bhambhani et al. (1992) elected to use the data collected from the cycle ergometry tests as the criterion value in their validity determinations. The mean $\dot{V}O_{2\,max}$ values from the wheeling trials were 38.6 ± 8.3 ml/kg/min and 39.2 ± 6.9 ml/kg/min as compared to 40.7 ± 5.6 ml/kg/min for the wheelchair ergometer trials and 39.7 ± 6.4 ml/kg/min for the cycling trials. The reported validity was low (.31 and .24 for each of the two respective trials). The reason cited was the small and unequal sample sizes that enhanced the variability observed within most participants between each trial. The cycle ergometer values were lower than those observed (45.0 ± 3.0 ml/kg/min) by Lundberg (1976). Despite small percentage differences and high reliability coefficients (r = .89 for the wheelchair ergometer trials and r = .93 for the bicycle ergometer trials), very few of the associated cardiorespiratory variables were reliable. The authors concluded that $VO_{2\,max}$ testing was an appropriate and reliable procedure. However, they recommend that testing should be function specific when choosing the mode of exercise for a given individual. In most cases if the person with CP/HI is ambulatory, then choose a LE testing mode such as a cycle ergometer. If the person is a wheelchair user or has low functioning lower limbs then a testing mode such as an arm ergometer would be most suitable.

Holland, Bhambhani, Ferrara, and Steadward (1994) examined the reliability of $\dot{V}O_{2\,max}$ and VT in a group of nine adults with CP/HI who were current or former athletes. These participants varied in classification from CP3 to CP7 (Appendix - 3). The participants performed two incremental tests on different days using either an arm crank or cycle ergometer, whichever was functionally appropriate. Five participants were tested in their own wheelchair on friction-free wheelchair rollers and the other four participants used a mechanically braked cycle ergometer. Holland et al. (1994) found high test-retest reliability for both absolute (r = 0.83) and relative (r = 0.79) $\dot{V}O_{2\,max}$, expired ventilation (r = 0.81), and the ventilatory equivalent for carbon dioxide (r = 0.79). Unfortunately, the authors found that the reliability of VT determinations was low (r = 0.26). This finding occurred even though the two independent evaluators showed great consistency. The authors suggested that the inherent variability in the spasticity experienced by the participants may have been responsible for the low inter-test reliability. Holland et al. (1994) questioned the appropriateness of using VT measurements in this population. Even though the participants in this study were current or former athletes, they were not necessarily experienced in testing situations.

Dwyer and Mahon (1994) evaluated VT and $\dot{V}O_{2\,peak}$ for a group of six current athletes with CP/HI. All their participants were ambulatory and were classed as either CP6, CP7, or CP8. The authors had the participants perform two maximal exercise tests, one on a treadmill and one on a cycle ergometer. The HR and $\dot{V}O_2$ at VT were not significantly different between the two modes of exercise. Overall, the maximal heart rates were within 97% of the participants' age predicted maximum. Peak oxygen consumption was significantly greater for the treadmill exercise, 55.7 ± 6.7 ml/kg/min than for the cycle ergometer, 50.1 ± 4.1 ml/kg/min. Oxygen consumption at VT occurred significantly closer to $\dot{V}O_{2\,peak}$ during the cycling test. These values were similar to values expected for reasonably well trained, able-bodied athletes. Given the low reliability of ventilatory measurements that Holland et al. (1994) and Bhambhani et al. (1992) found in this population, it is unfortunate that Dwyer and Mahon (1994) did not also attempt to determine the reliability of their performance measurements. Dwyer and Mahon's (1994) study did not include the lower class participants (CP3-5), so the participants in their study would have been less affected by spasticity. Therefore, it is not surprising that Dwyer and Mahon (1994) found greater test retest reliability than did Holland et al. (1994) or Bhambhani et al. (1992)

Lundberg conducted a number of studies in the 1970s examining the mechanical efficiency of children and young adults with CP/HI (Lundberg, 1975). In 1975, Lundberg reported on a group of young adults with CP/HI. Six of the 10 presented with primarily dyskinesia or ataxia and the remaining 4 presented with spasticity (either diplegia or triplegia). The author found the participants with ataxia tended to pedal at the same rate and performed at a similar mechanical efficiency (21.1%) as did the able-bodied controls (22.2%). However, the mechanical efficiency was significantly lower for participants with spasticity than those without spasticity. The participants with spasticity also pedalled at a significantly slower rate, 48.9 rpm compared to 52.9 rpm for participants without spasticity. In a follow up study using cycle ergometry and a physical work capacity at a heart rate of 170 bpm, Lundberg (1976) reported a decrement of 50% in the net mechanical efficiency of the participants with CP/HI compared to able-bodied controls. In addition, the author found that the average $\dot{V}O_{2\,max}$ was 12% less than the age-matched controls. It appeared that participants with a medical diagnosis of CP/HI did not adapt to exercise in the expected able-bodied fashion. Lundberg (1975) and others speculated that the quality and quantity of spasticity plays a major role in how these people respond and potentially adapt to an exercise stimulus. Specifically, spasticity during an exercise bout may impair some level of regional blood flow (Bhambhani et al., 1992; Ferrara & Laskin, 1997; Holland et al., 1994). Bhambhani et al. (1992) and Holland et al. (1994) both suggested that this blood flow dysfunction may help explain the low reliability observed for their VT measurements. Similar to the SCL population there are apparently some "lesion level" dependent factors, such as the amount of spasticity, available range of motion, and coordination of movement.

Spinal Cord Lesion and Muscular Strength Training

There is a paucity of literature regarding the ability of adults with SCL to adapt to strength training programs (Shephard, 1990). Traditional, Delorme type (Delorme, 1945) strengthening programs have been at the core of rehabilitation programs for people with SCL since the early twentieth century (DePauw & Gavron, 1995). Early research involving strength programs for people with paraplegia reported significant improvements in maximal dynamic strength and muscular endurance following a short term (seven weeks) traditional resistance training program (Nilsson, Staff, & Pruett, 1975). In a later study, Groeneveld (1986), using Nautilus equipment and participants with paraplegia, reported significant improvements (3% to 221%) in strength after a six week training program.

Davis and Shephard (1990) used isokinetic dynamometry to assess strength and power gains after 16 weeks of 3 days per week arm ergometry aerobic endurance training. The authors recruited 15 previously sedentary men with paraplegia. Even though the participants participated in an aerobic training protocol their power for both shoulder extension and elbow flexion increased significantly. Due to the principle of specificity of training, an increase in muscular power would not be the expected result from sedentary individuals participating in an aerobic endurance training protocol.

Much of the resistance training information for programming to date has employed traditional strength training prescriptions of three sets of six to ten repetitions for each exercise, applying progressive overload when the upper range of the prescribed repetitions is obtained (Green, 1996, pp. 49-50; Somers, 1992, pp. 89-90). The published literature focuses on functional activities, how to perform exercises, general disability specific indications, and contraindications (Laskowski, 1994; Lockette & Keyes, 1994). Unfortunately, there has been little research that has focussed on the adaptations and responses to resistance training in the SCL population (Figoni, 1997; Frey, 1975; Hoffman et al., 1994; Mange, Ditunno, Herbison, & Jaweed, 1990; Noreau & Shephard, 1992; O'Connell & Barnhart, 1995).

Cerebral Palsy/Head Injury and Muscular Strength Training

Very little information on resistance training for the CP/HI population is available. Winnick and Short (1991) reported the results of a study completed in 1986 that investigated children with CP/HI. The testing included strength exercises (hand grip and pull-ups), muscular endurance exercises (curl-ups), and power activities (standing broad jump). They found that these children ranked significantly lower in muscular strength compared with a matched able-bodied group. Possible reasons for these findings were: 1) environmentally related or 2) disability related. These children may have scored poorly because either the test items or equipment were inappropriate, or alternatively, there were some unknown inherent disability related issues.

Horvat (1987) reported the results of a case study that evaluated the progress of a 21 year old man with spastic hemiplegia during an eight-week training program. The participant was trained with a combination of free weights and machine weight systems, and then tested isokinetically. The resistance of each exercise was adjusted so that the client could successfully complete 10 repetitions. Ten pounds of resistance and five repetitions were added to each exercise after the second and sixth weeks. The intensity of the program was intentionally kept low. After the eight weeks of training the participant demonstrated improved isokinetic strength in all test movements on both the involved and the uninvolved sides. From the duration and intensity of this program it would be assumed that only neuromuscular adaptations occurred.

Holland and McCubbin (1994) evaluated the reliability of both concentric and eccentric isokinetic testing on adults with CP using the Kin-Com isokinetic dynamometer. The authors recruited 14 individuals with diverse functional limitations related to their CP. During each of the three testing sessions peak and average torque at 60°/s was determined for shoulder adduction/abduction and knee flexion/extension. As expected due to the varied nature of spasticity, the variance between trials was low (0.0% - 5.8%), but quite high between sessions (8.5% - 65.8%). However, the generalizability coefficients met the requirements for good to high reliability (r = .79 - 96). Holland and McCubbin concluded that isokinetic testing is a reliable measure of average and maximal strength, but emphasized that the initial orientation session was an essential component of their protocol.

Tripp and Harris (1991) also evaluated the test-retest reliability of isokinetic knee flexion and extension for 20 adults with spastic hemiplegia. They collected data from five repetitions on two occasions. The authors reported intraclass correlation coefficients (ICC) of ≥ .90 for both the involved and uninvolved sides. This and other studies have made the case that it is both appropriate and necessary to train and assess strength in people with CP/HI (Bohannon, 1989; Bohannon & Larkin, 1985; Bohannon, Larkin, Smith, & Horton, 1987; Bohannon & Smith, 1987; Bohannon & Walsh, 1992; Ferrara & Laskin, 1997; Palmer-McLean & Wilberger, 1997).

In summary, people with physical disabilities can and do adapt to both aerobic endurance and muscular strength exercises. Until recently, the literature has focussed on comparing the able-bodied population to people with physical disabilities. This deficiency of information regarding adaptations to both strength and endurance training is likely to affect the quality of treatment programs in the rehabilitation setting, the variety and effectiveness of recreational fitness programs, and ultimately the performance of the elite athlete.

Simultaneous Training for Muscular Strength and Aerobic Endurance

The term "interference effect" was introduced by Hickson (1980) to describe the results of his concurrent training study. The purpose of the study was to observe the physiological adaptations produced from training for strength (S) or endurance (E) separately, as compared to a combined regimen (S&E). The participants were exposed to very high intensity LE strength and endurance training programs. During the first seven weeks of training the S&E group showed similar adaptations in the measured one repetition maximums (1RM) and $VO_{2\,max}$ when compared with the S and E only groups. After a further three weeks of training the S&E group showed no further increases in their strength adaptations. By the 10th week, the author noted a slight decline in strength in the S&E group, whereas the S group continued to improve. From these observations, Hickson reported an antagonistic effect between the two modes of exercise in the S&E group. Hickson did not observe any discrepancies in the development of aerobic endurance between the S&E and E groups. He also suggested that the following conditions must be met in order to investigate the existence of the interference effect: 1) both the S and E must involve the same muscle groups, 2) both the individual S and E programs must be specifically designed to result in their respective specific adaptations, and 3) the expected magnitude of change must be large enough so that any differential response can be detected.

Several other studies have come to conclusions similar to those reported by Hickson (1980). Dudley and Djamil (1985) used an isokinetic dynamometer for strength training and cycling for aerobic endurance training in their seven week study. They reported that the S group, solely strength trained, demonstrated angle specific torque increases in all but the fastest of the six test velocities, whereas the S&E group showed similar significant increases for only the isometric tests and the two slowest test velocities. Dudley and Djamil (1985) concluded that Hickson's (1980) interference effect was observed in the S&E group with the selective inhibition of strength at the three greatest test velocities. Hunter et al. (1987) found that LE muscular strength and power gains in their previously untrained S&E group were significantly less than in the group that trained for strength alone. The LE 1RM declined in the S&E group after the tenth week of combined training.

Hunter et al. (1987) followed a 12 week training format and recruited untrained participants for the traditional three training groups (S, E and S&E). They also added a second combined training group that was highly endurance trained. Hunter et al. (1987) noted that the highly trained S&E group did not demonstrate any aerobic endurance adaptations while performing endurance training combined with strength training during the 12 week training program as measured by $VO_{2\,max}$. In addition, they observed similar strength and power improvements between both the S and highly trained S&E groups. Because the aerobic endurance training stimulus was based on percent HR and the training intensity was consistent across groups, the authors concluded that the highly trained S&E group's cardiovascular system was not challenged. The highly trained S&E group was actually only maintaining their aerobic endurance whilst stimulating their neuromuscular system to adapt through the strength training component of the program. Therefore, Hunter et al. (1987) hypothesized that any potential interference effect may be mediated by the relative training intensity. Although all the strength training groups demonstrated improvements in muscular strength, the S&E group's increases were diminished as compared to the highly trained S&E and S groups in both the 1RM bench press and squat exercises. This would indicate the existence of potential interference effects both in muscle groups that were actually being trained for both strength and endurance as well as muscle groups that were only experiencing a strength training stimulus. This would be contrary to Hickson's (1980) suggestion that for an interference effect to occur a given muscle group must experience both strength and endurance training stimuli.

Zehr and Bell (1996) reported a predisposition to diminished strength gains based on the pre-study strength values of a group of rowers, who trained six days per week for 16 weeks. At the conclusion of their study the authors separated the 56 participants into two groups: 1) participants who demonstrated a diminution in strength gains during the final eight weeks of the study, and 2) participants who continued to improve during the second half of the study. They discovered that participants who demonstrated attenuation in strength gains also had greater pre-study strength values as compared to those who continued to improve. Individuals with higher levels of strength prior to the onset of a combined training program appeared more likely to experience an interference effect. However, the lessened strength adaptations observed may also be explained by a biological ceiling effect for the given strength training exercise.

Hennessy and Watson (1994) compared three different preseason training programs with a group of 41 rugby players. After eight weeks of training the S&E group demonstrated similar significant improvements in running performance as the E group. However, the S&E group showed a lessened strength training response and no improvements in power or speed as compared to the S group.

Hortobágyi et al. (1991) recruited 28 young men from the United States Army ROTC program. These participants completed a 13 week program of either a high or low resistance training on hydraulic resistance exercise equipment. After every workout both training groups completed a 2 mile run. The authors reported that although the improvements in strength and run performance were independent of the type of resistance used during the training program they found that compared to a previous study using the same cohort of participants the strength gains were compromised by the inclusion of the run training.

Bell et al. (1991) were the first to use trained rowers as participants in a concurrent strength and endurance training study. The athletes strength trained using low velocity hydraulic resistance and endurance trained on a rowing ergometer. These authors reported a lessened response for the S&E group in the total work, peak torque and knee extensor cross sectional area as compared with the S group at the conclusion of the 12 week training study. This was the first concurrent training study to use computerized tomography to evaluate skeletal muscle cross-sectional area. The muscle cross-sectional area data suggested that any lessened response of strength adaptations with concurrent training may result in part to an impaired ability of skeletal muscle to hypertrophy. Common to all these studies that demonstrate an attenuation in strength development is that the antagonism seems to appear after a minimum of seven weeks of training, with relatively high training intensities, and without any significant effect on the development of aerobic endurance.

Other research has provided additional support for the hypothesis that training for aerobic endurance may lessen the physiological adaptations to training for muscular strength. Sale, Jacobs, et al. (1990) compared two different regimens of combined strength and endurance training. They found that both forms of S&E groups demonstrated some attenuation of the adaptations to strength as compared with the S group. However, the S&E group performing both modes of exercise on the same day demonstrated smaller changes in strength development in comparison to the S&E group that trained for each mode on separate days. Sale, Jacobs, et al. (1990) also observed a significant decrease in capillary density with both types of training despite a significant increase in citrate synthase activity. These findings demonstrated diminished strength gains in the S&E group and suggest that the antagonism may be occurring at the cellular level.

In contrast, other studies do not support the existence of an antagonism in strength gains with concurrent aerobic and resistance training. Sale, MacDougall, et al. (1990) reported no interference in the development of either muscular strength or aerobic endurance after 22 weeks of concurrent strength and endurance training. This lack of antagonism was apparent in the similarities of many of the biochemical, histochemical, morphological and performance measures. These results, however, may have been confounded by using a single-leg training model. When using a single-limb training model, where the participant was their own control, cross transfer of training effects may occur (Bell, Neary, & Wenger, 1988). In addition, by using this model, any hormone-mediated responses (e.g., cortisol and testosterone) cannot be controlled.

Nelson et. al. (1990) found no attenuation of strength gains after 22 weeks of concurrent endurance and isokinetic resistance training when compared to resistance training alone. However, they did observe an antagonism in improvements of both $\dot{V}O_{2\,max}$ and citrate synthase activity. Based on their observations these researchers suggested that aerobic endurance, and not peak torque, may be hindered with concurrent training. It is important to note that the authors reported methodological problems with their strength assessment at the midpoint of training.

McCarthy et al. (1995) found that the S&E group demonstrated significant improvements in strength and aerobic endurance. The gains in strength were similar to those observed in the S groups and the gains in endurance were similar to those observed in the E group. This study recruited 30 sedentary young men who participated in an three day per week exercise program for 10 weeks.

Hickson et al. (1988) showed that short-term run and cycle endurance time to exhaustion and long duration cycling time to exhaustion were increased after resistance training and "steady-state" endurance training in previously endurance trained participants. This study, however showed no changes in $\dot{V}O_{2\,max}$, muscle morphology or citrate synthase.

A more recent study by Kraemer et al. (1995) attempted to overcome many of the difficulties and criticisms of previous research. They recruited 40 well trained young men from specialized military units. These men were expected to tolerate a high intensity training regimen. The authors were able to control the participants' exercise, rest, and diet during the 12 week study. They also used the two to three weeks before the onset of the study to familiarize the participants with all of the testing procedures. Kraemer et al. (1995) performed muscle biopsies to examine cellular adaptations, and collected blood and urine to evaluate the acute and chronic hormonal adaptations in relating to the concurrent exercise training. Finally, these authors used two S&E training groups. One group followed the traditional methodology of completing both the strength and endurance training programs. The second group exclusively strength trained the UE and endurance trained the LE. Kraemer et al. (1995) found that the traditional S&E group significantly improved in both endurance and strength performance measures. However, the traditional S&E group's improvements were smaller, though not significant, than those observed in the hybrid S&E group. These lesser responses were most apparent for the LE strength measures. The alternate combined training group appeared to respond as if they were single mode training, therefore supporting Hickson's (1980) notion that interference may be localized to the muscle groups experiencing the combined training stimulus. The authors also noted a differential response in fiber type and hormone adaptations to the different training programs. Type I fiber hypertrophy was diminished in the S&E group as compared to the S group, and the Type IIc fibers in the S&E group did not decrease in area to the same degree as they did in the E group. The authors recommended that the most effective way to optimize a training response was to use a single mode protocol.

Bell, Syrotuik, Burnham, Martin, and Quinney (2000), Bell, Syrotuik, Socha, Maclean, and Quinney (1997), and Horne, Bell, Fisher, Warren, and Janowska-Wieczorek (1997) all reported partial support for an interference effect. Bell et al. (2000) found that though LE strength, as measured by knee extension 1RM, increased for both the S&E and S groups, the improvement in knee extension was substantially greater in the S group. The improvement in leg press 1RM was similar between S&E and S groups. The authors reported no significant changes in free testosterone concentrations between the training groups, but there was a significant increase in urinary free cortisol for the S&E group. Bell et al. (1997) reported differential responses between men and women in strength and hormonal responses with both S&E and S formats of training. The authors reported significant gender differences in all of the following measurement variables: 1RM incline leg press, 1RM bench press, serum testosterone, urinary free cortisol, VT, and $\dot{V}O_2$. As in the study by Bell et al. (2000) no changes in serum testosterone were detected in either training group, nor between genders. However, the male participants in the S&E group demonstrated increased cortisol concentrations in the eighth week through to the completion of the study. In contrast, by the eighth week the women in the S group presented a decrease in cortisol levels. By the completion of the training program the women in both the S and S&E groups exhibited increased cortisol levels as compared to their pre-training levels. The strength gains for the men were similar for both training groups, whereas the leg press 1RM gains for women in the S&E group were lower than those in the S group. Horne et al. (1997) found that the women in the S&E group presented with significant increases in urinary free cortisol and no significant decrements in strength, whereas the men presented with no change in their hormonal status, but lessened lower extremity strength gains.

The controversy regarding the physiological adaptations to concurrent endurance and resistance training may be partially explained by differences in experimental designs. Resistance training has varied in mode:

1) traditional weight training, versus velocity controlled
2) training durations from 6 to 22 weeks
3) training volumes
4) participant samples (non-athletes versus athletes)
5) training models (traditional versus a one-legged training model)

Endurance training programs have included interval training or continuous training, with differences in intensity, duration and frequency of training. The inconsistencies in the training protocols of the cited studies makes it difficult to accurately compare and contrast the research to date.

One criticism of the concurrent strength and endurance training literature may be that the combined training group experienced "over training." The studies could have dealt with this issue by assessing chronic levels of creatine kinase and the testosterone/cortisol ratio. If the levels of creatine kinase remain within normal limits then the evidence for chronic muscle damage would be minimized (Graves, Clarkson, Litchfield, Kirwan, & Norton, 1987; Houmard et al., 1990). In addition, the testosterone/cortisol ratio could be used to evaluate the anabolic or catabolic state of skeletal muscle (Viru, 1992; Wheeler, Wall, Belcastro, & Cumming, 1984). Given that the balance stays neutral or tends toward the anabolic end of the continuum, the argument for the antagonism in concurrent training, as one of simple overtraining, may be rejected.

The lack of information about possible positive and negative implications of concurrent training programs in the physically disabled population has already been addressed. This lack of information regarding both strength and concurrent strength and endurance training likely affects the quality of treatment programs in the rehabilitation setting, the variety and effectiveness of recreational fitness programs, and possibly the performance of the elite athlete.

Hormonal Adaptations to Muscular Strength and Aerobic Endurance Training

Training for either muscular strength or aerobic endurance results in the stimulation of the endocrine systems (Fellmann, 1992; Kraemer, 1992c). It has been hypothesized that the endocrine response is critical for both centrally and peripherally mediated exercise adaptations. It has also been suggested that many of the hormonal responses and resulting adaptations to exercise are exercise mode specific (Fellmann, 1992; Kraemer, 1992c). The following is a brief review of the function and action of the most commonly observed hormones.

The hormone testosterone is an important regulator of protein synthesis in skeletal muscle and has been positively related by some researchers to the increases in muscle hypertrophy observed after resistance training (Adlercreutz et al., 1986; Häkkinen, 1989; Viru, 1992). Total testosterone concentration is mediated by the hypothalamic-pituitary-teste/adrenal axis in both men (testes) and women (adrenal glands) (Schwab, Johnson, Housh, Kinder, & Weir, 1993). Acute increases in unbound serum testosterone concentration have been shown to result from moderate resistance training, as well as aerobic endurance training in the untrained able-bodied individual (Hackney, 1989; Hoffman, 1992; Schwab et al., 1993). However, this elevated testosterone concentration tends to be relatively short lived following an acute endurance stimulus as compared to a resistance training session (Schwab et al., 1993) Several researchers have noted that plasma levels of testosterone remain elevated with moderate to high intensity resistance training programs (Alén, Pakarinen, Häkkinen, & Komi, 1988; Hoffman, 1992). However, Häkkinen, Keskinen, Alen, Komi and Kauhanen (1989) have also reported that high intensity, long term strength training results in a decrease in testosterone concentration. Circulating levels of testosterone may remain relatively unchanged, or as suggested in some studies, may actually decrease as a result of chronic endurance training (Fellmann, 1992; Houmard et al., 1990; Viru, 1992).

Luteinizing hormone and follicle stimulating hormone are hormones that stimulate the adrenal glands and testes to produce testosterone from cholesterol. These two hormones are produced in the pituitary gland and are mediated by gonadotropic releasing hormone (Guyton & Hall, 1996, p. 1013). The secretion of gonadotropic releasing hormone from the hypothalamus into the circulatory flow and on to the pituitary gland is stimulated with every strength training session (Kraemer, 1992a, 1992b). With participants in a strength training program, the pulse frequency and concentrations of luteinizing hormone and follicle stimulating hormone are significantly increased, and this mediates the increase in testosterone production (Kraemer, 1992a, 1992b). No increases in circulating luteinizing hormone or follicle stimulating hormone have been observed with endurance training (Fellmann, 1992). Overall, it appears that a combination of the mode, intensity, and duration of a given exercise prescription determines the concentration of circulating testosterone.

Sex hormone binding globulin and albumin are the proteins that bind with testosterone and allow it to circulate in the systemic blood supply (Pugeat et al., 1991). Normally about 97% of the testosterone is bound to these proteins. The other 3% is in the unbound/bioactive form and is available to stimulate protein synthesis at the muscle fibre level (Häkkinen, 1989; Viru, 1992). With strength training, the percentage of testosterone in the unbound state has been shown to increase, whereas with endurance training no change was shown (Kraemer, 1992a, 1992b). Whether total testosterone increases or not, an absolute or relative increase in the concentration of the unbound form of serum testosterone suggests the potential for skeletal muscle hypertrophy (Schwab et al., 1993; Vervoorn et al., 1991).

With a strength training stimulus it has been demonstrated that the percentage of free testosterone may increase. An increase in the percentage of unbound testosterone in the serum has been associated with enhanced stimulation of skeletal muscle growth (Vervoorn et al., 1991; Viru, 1992). Strength training may also increase the absolute amount of testosterone being produced (Vervoorn et al.; Viru, 1992). With strength training the following adaptations of testosterone may be observed:

1) an absolute increase in total testosterone and only a relative increase in the free form,

2) an absolute increase in total testosterone and an absolute increase in the percentage of the free form, and

3) no change in the absolute level of the total testosterone, but an increase in the percentage of the free form.

The evaluation of the plasma levels of both total testosterone and unbound testosterone must be performed to ensure that this adaptation to training is not overlooked (Bell, et al., 1991; Kraemer, 1992c; Viru, 1992)

Endurance training studies have shown either the maintenance of pre-training total serum testosterone concentration or a slight decrease (e.g., Adlercreutz et al., 1986; Hackney, 1989; Viru, 1992). It appears that the percentage of free testosterone remains unchanged (Adlercreutz et al.; Häkkinen, 1989; Viru, 1992).

Cortisol is the major glucocorticoid that is produced by the adrenal cortex. Increased circulating concentrations of cortisol have been related to catabolism of connective tissue and collagen (McArdle et al. 1996, p. 365). Physical and/or emotional stress may cause the hypothalamus to secrete corticotropin-releasing factor which results in the production of corticotropin by the anterior pituitary gland. Corticotropin stimulates the adrenal cortex to produce and release cortisol into the circulatory system (Neary, Wheeler, Maclean, Cumming, & Quinney, 1994). The importance of cortisol is not in its individual measurement, but rather in its ratio with testosterone (Deschenes, Kraemer, Maresh, & Crivello, 1991; Neary et al., 1994). When this ratio favors testosterone the body is considered to be in an anabolic state, as occurs with strength training. This ratio is 1:1 during the normal unstressed state. Even with the stress of moderately intense aerobic endurance training or strength training program maintenance this ratio remains stable (Kraemer, 1992a, 1992b). However, when the ratio is in favor of cortisol, this usually defines an elevated catabolic or stressed state, which could be a result of disease or overtraining in strength or endurance (Alén et al., 1988; Hickson & Marone, 1993; Neary et al., 1994). Protein breakdown and muscle atrophy have been observed during periods of long-term, high concentrations of plasma cortisol. In addition, an acceleration of lipid metabolism has been demonstrated, which could be associated with intense exercise and/or starvation (Alén et al., 1988; Hickson & Marone, 1993; Neary et al., 1994). For research purposes, cortisol can be detected both in the plasma and in the urine. Due to the highly variable nature of cortisol concentration in the blood, the best method would be to determine cortisol concentrations from a 24 hour urine collection (Cumming & Wheeler, 1990; Neary et al., 1994).

Neary et al, (1994) designed a seven week high intensity endurance training study with club-level cyclists to specifically evaluate the efficacy of using urinary free cortisol as an indicator of overtraining. They found no significant changes in the concentrations of serum free testosterone, whereas there was a significant increase in the urinary free cortisol by the third week of the training program. Overall the serum free testosterone/urinary free cortisol ratio significantly decreased for the participants in this study. Neary et al. (1994) concluded that urinary free cortisol should be considered further as a useful tool in evaluating exercise training stress.

Kraemer et al. (1995) examined the adaptations of serum testosterone and urinary free cortisol to acute single mode exercise bouts and training for muscular strength and aerobic endurance simultaneously. In terms of the hormone specific results, they found no significant changes in the measured total testosterone levels across groups over the 12 week training period. The authors found significant increases in resting cortisol concentrations in the S&E group during the 8th and 12th week testing periods, promoting a potential catabolic environment. There was a differential response to the acute exercise responses of both testosterone and cortisol between experimental groups. Of note was the increased acute response in testosterone concentrations in the S as compared to the S&E group. These findings suggested that if there was an attenuation of the strength development in the S&E group it may have been caused by some level of overtraining and should be investigated further. However, isolated increased levels of circulating cortisol does not necessarily imply overtraining. Specifically, the authors suggested analysis at the molecular level in order to understand protein metabolism.

Bell et al. (1997), using previously trained individuals, found no significant changes in serum testosterone during a 16 week strength and combined strength and aerobic endurance training study. Their study detected a differential response in urinary free cortisol concentrations based on gender, and not between the designated exercise training groups as might be expected. There was a significant elevation in the cortisol concentrations by the eighth week for the men in both the S and the S&E groups. By the 16th week this elevated level subsided to pre-training levels in the S group and was maintained in the S&E group. For the women, both the S&E and S groups showed significant increases in urinary free cortisol by the 12th week, and this elevation continued through to the end of the study. Even though the women and men in the S&E groups demonstrated elevated cortisol levels during the later portions of this study, the researchers stated that interference of the strength training adaptations cannot be assumed. The difference in leg press gains between the women's S and S&E groups were pronounced, but not significant. There was no significant difference between the men's groups. Regarding an interference effect, this may have been a simple case of overtraining because the S&E groups did both strength and endurance training on the same days three times per week instead of spreading out their training programs over five or six days.

Bell et al. (2000), reported that there were no changes in the serum concentrations of testosterone, sex hormone binding globulin, or human growth hormone. They found both elevated cortisol concentrations and a lessened strength response in knee extension 1RM for the S&E group compared to the S group. Though a diminished response was reported it still represented a significant improvement in leg strength. This significant increase in the leg press 1RM was similar for both strength training groups. This study provides some evidence for the existence an antagonistic effect when training simultaneously for muscular strength and aerobic endurance.

It seems likely that this area of hormonal research will eventually play an important role in the explanation of the mechanism of the presence or the absence of a exercise mode specific interference effect. No literature has been found that investigated either the long term or acute effects of muscular strength or aerobic endurance training on hormonal adaptations for people with physical disabilities.

CHAPTER III
METHODS AND PROCEDURES

Participants

The participants were recruited from the approximately 140 people with various types and severities of physical disabilities who attended The Steadward Center at the University of Alberta. This pool of potential participants reflects a sample of convenience. A statement of the proposed study was circulated and all interested persons had the study verbally explained to them. Each participant signed the informed consent form as approved by the Faculty of Physical Education and Recreation Human Ethics Committee (see Appendix - 4). All potential participants were screened for musculoskeletal problems, such as chronic rotator cuff dysfunction, that might predispose them to exercise related injuries. All of the participants had some limited experience in an organized exercise program, although none had undergone comprehensive physiological testing.

Prior to their random assignment into one of the four experimental groups, the 37 people who volunteered for this study were stratified by gender and a disability specific sport classification. The stratification process was performed to facilitate an even distribution of gender and disability types across the experimental groups. This process was necessary due to the small sample size used in this study. The classification systems selected for use in this study are traditionally used for the classification of athletes in track and field as well as in cycling. The CP/HI system was historically used for swimming as well. Even though the participants were not athletes, disability specific sport classification systems were used because they classify the individuals by their functional abilities versus the medical model of labeling the severity of their condition. Participants with CP/HI were classified using the Cerebral Palsy - International Sport and Recreation Association functional profile classification system (DePauw & Gavron, 1995), (see Table A3-1). Participants with multiple sclerosis (MS) or SCL who ambulated were classified by the International Sport Organization for the Disabled's Les Autres classification system (DePauw & Gavron, 1995), (see Table A3-2) and were considered a third "other" disability type in the data analysis. Participants with SCL and were wheelchair dependent were classified using the International Stoke Mandeville Wheelchair Sports Federation functional track classification system (DePauw & Gavron, 1995), (see Table A3-3). An individual not associated with the study randomly assigned participants to the four training groups. The four training groups consisted of muscular strength training only (S; n = 10), aerobic endurance training only (E; n = 10), combined strength and endurance training (S&E; n = 8), and a control group (C; n = 9). A complete description of the participant characteristics is given in Tables 3-1 and 3-2.

Table 3-1

Demographics for the Strength Training (S), Endurance Training (E), Combined Strength and Endurance Training (S&E), and the Control (C) Groups

Group	Gender	n	Age (years)[a]	Mass (kg)[a]
S	Female	3	45.7 ± 11.0	74.8 ± 23.8
	Male	7	27.3 ± 6.6	67.8 ± 21.4
E	Female	3	38.0 ± 3.6	61.9 ± 8.6
	Male	7	33.6 ± 6.6	80.1 ± 10.3
S&E	Female	2	24.5 ± 5.0	62.5 ± 1.4
	Male	6	31.2 ± 12.9	75.6 ± 14.6
C	Female	5	32.4 ± 5.0	68.2 ± 27.1
	Male	4	43.3 ± 20.7	79.8 ± 27.9

Note. [a] Mean ± standard deviation.

Study Design

This 12 week study followed a repeated measures design. Once randomly assigned to a group the individual stayed in that group for the duration of the study. All of the dependent measures were evaluated separately for the three training groups prior to the onset of the study (pre-test), during week 6 (mid-test), and at the end of week 12 (post-test). Though not desirable, due to funding limitations the C group was only assessed pre-test and post-test.

Each treatment group followed a non-linear periodized 12 week training program. Within the framework of the overall training method of the group,

Table 3-2

Medical Disability, Mode of Mobility, and Sport Classification for the Strength Training (S), Endurance Training (E), Combined Strength and Endurance Training (S&E), and the Control (C) Groups

Group	Gender	Disability Type[a]	Mode of Mobility[b]	Class[c]	Group	Gender	Disability Type[a]	Mode of Mobility[b]	Class[c]
S	Female	CP/HI	LE	CP7	S&E	Female	CP/HI	LE	CP7
	Female	CP/HI	LE	CP5		Female	CP/HI	LE	CP7
	Female	MS	LE	L4		Male	CP/HI	LE	CP8
	Male	CP/HI	LE	CP5		Male	CP/HI	LE	CP8
	Male	CP/HI	LE	CP5		Male	CP/HI	LE	CP5
	Male	CP/HI	UE	CP4		Male	CP/HI	UE	CP4
	Male	CP/HI	UE	CP3		Male	Paraplegia	UE	T3
	Male	Paraplegia	UE	T4		Male	Central Cord	UE	L6
	Male	Paraplegia	UE	T3					
	Male	Polio	LE	L5					
E	Female	CP/HI	UE	CP3	C	Female	CP/HI	LE	CP6
	Female	CP/HI	UE	CP3		Female	CP/HI	UE	CP4
	Female	Polio	UE	T4		Female	CP/HI	UE	CP3
	Male	CP/HI	LE	CP8		Female	CP/HI	UE	CP3
	Male	CP/HI	LE	CP7		Female	Tetraplegia	UE	T2
	Male	CP/HI	UE	CP4		Male	CP/HI	LE	CP8
	Male	Paraplegia	UE	T4		Male	CP/HI	LE	CP7
	Male	Tetraplegia	UE	T1		Male	CP/HI	LE	CP7
	Male	Tetraplegia	UE	T1		Male	CP/HI	LE	CP7
	Male	MS	LE	L6					

Note. [a] Cerebral Palsy/Head Injury (CP/HI), Multiple Sclerosis (MS), Polio Myelitis (Polio).[b] LE = ambulatory, UE = wheelchair user.
[c] Disability specific International track and field classification (DePauw & Gavron, 1995)

participants were given individualized training programs which took into account their functional abilities and fitness levels, based on their pre-test results. The members of the C group were requested to continue their current exercise regimen at a maintenance level. The C group participants were also requested to record each exercise session in a log book provided by the investigator. All participants were requested to refrain from any new physical activity without the consent of the investigator. The 10 days before the start of the training program were used for familiarization with the testing equipment and protocols, as well as the initial testing.

Testing Schedule

The three (pre-test, mid-test, and post-test) testing sessions occurred during the week before the onset of training, the first three days of week seven, and the week following the cessation of training, respectively (see Table 3-3). Two full days of rest were scheduled after the last training session before the mid and post-study testing sessions. All tests for any given participant were scheduled at the same time each day throughout the duration of the study to reduce any diurnal influences across the three testing sessions.

Body Composition

Skinfold measurements, girths, and weight were all assessed using the standard methods as described by Ross and Marfell-Jones (1987, chap. 6) and

Table 3-3

Testing Schedule for the Strength Training (S), Endurance Training (E), Combined Strength and Endurance Training (S&E), and the Control (C) Groups During the 12 Weeks of Training

Group	Pre-test (week 0)	Mid-test (week 6)	Post-test (week 12)
S	✓	✓	✓
E	✓	✓	✓
S&E	✓	✓	✓
C	✓	✗	✓

Note. ✓ denotes all test items were scheduled. ✗ denotes no test items were scheduled.

Roche (1996). To facilitate the diagnostic ultrasound procedures, the upper arm girth was measured at the midway point between the acromion process and the olecranon. The thigh girth was measured from a point 10 cm proximal to the base of the patella. For the purposes of this study the following sum of three skinfolds sites were selected: biceps brachii, triceps brachii, and subscapular. All skinfold and girth sites were permanently marked with silver nitrate and were re-marked as necessary.

Strength Testing

The 1RM for elbow flexion (bilateral biceps curl) and knee extension (double leg press - ambulatory participants only) were determined using a standard four set approach adapted from Gotshalk (1985). This protocol was designed to have the participant reach volitional failure during the second repetition of the fourth set, thus determining the 1RM for that exercise. The first (warm-up) set consisted of six to eight repetitions at 40% to 50% of the estimated 1RM. The following three sets progressed in a pyramid fashion of decreasing repetitions and increasing resistance. Throughout this procedure the participant was consulted as to how many repetitions they thought they could have performed in order to ensure that the 1RM was determined within the four set framework. The testing was performed on the same equipment used during the training sessions. The technique criteria of full functional range of motion, no rest between repetitions, and equal concentric and eccentric movement rates were strictly enforced using a metronome. All participants received consistent verbal encouragement. A 2-3 minute rest period was enforced between sets.

The Second Ventilatory Threshold and Peak Oxygen Consumption Determinations

Peak oxygen consumption and VT2 were assessed following a continuous protocol of progressive workloads using a Horizon Metabolic Measurement Cart (Sensormedics, CA) and open circuit spirometry. Arm cranking was performed at a cadence of 50 rpm on a Isokinetic Upper Body Exerciser (Cybex, Chattanooga, TN) with the initial load set at the dynamometer's minimum load of 25 W and increased every 2 min until volitional fatigue was reached. For the participants with quadriplegia, Lasko-McCarthey and Davis (1991) and previous pilot work and has shown that 5 to 10 W increases were appropriate for an 8 to 14 min testing protocol. For participants with paraplegia and CP/HI, previous work by Bhambhani et al. (1992), and Holland et al. (1994) demonstrated that 10 to 15 W increases were appropriate for an 8 to 14 min testing procedure. Leg cycling was performed on a Monark 818 cycle ergometer at a cadence of 50 rpm with the initial load set at 25 W and increased by either 12.5 W or 25 W every 2 minutes until volitional fatigue was reached. The choice of load increases were based on the reported fitness levels and the initial HR responses during the first two exercise loads. The goal was to have each participant reach volitional fatigue in 8 to 14 min (Holland et al., 1994). Throughout the testing procedure the participants received consistent verbal encouragement.

The second ventilatory threshold was determined by the pulmonary ventilation/carbon dioxide production ($\dot{V}_E/\dot{V}CO_2$) versus power output relationship and was assessed by locating the minimum point on the $\dot{V}_E/\dot{V}CO_2$ versus power output curve (Bhambhani & Singh, 1985). During the actual test VT2 was estimated at the power output where an abrupt increase in V_E and an increasing $\dot{V}_E/\dot{V}O_2$ was observed. When this estimated VT2 was observed the final power output stages were decreased to one minute to hasten the determination of $\dot{V}O_{2\,peak}$. Heart rates were monitored using a Polar Favor heart rate monitor (Polar Electro, Sweden). Prior to the onset of the study, the VT2/$\dot{V}O_{2\,peak}$ procedure was completed twice to assess the reliability of the measurements and ensure a stable baseline. If the difference between the first two tests was greater than five percent, a third test was completed (Shephard, 1992, p. 198). The primary subjective criterion for $\dot{V}O_{2\,peak}$ was the volitional stoppage of the test by the participant. The participant was asked to maintain the prescribed cadence for as long as possible. The primary objective criteria was a plateau in peak HR during the final stages of the testing protocol. The secondary objective criteria was a respiratory exchange ratio (RER) of > 1.10. All metabolic values displayed by the Horizon Metabolic Measurement Cart were presented as an average of the previous 15 seconds.

The reliability of the method of determining VT2 in individuals with CP (Holland et al,. 1994) and those with SCL (Davis, 1993) and $\dot{V}O_{2\,peak}$ in participants with SCL (Bhambhani, Eriksson, & Steadward, 1991) and participants with CP (Holland et al., 1994; Bhambhani et al., 1992) has been well documented. The pilot study conducted by the author showed excellent stability across the three pre-study evaluations and two post-study evaluations. Intraclass Correlation Coefficients (ICC) [Model 2, single ratings] of > .92 were found (see Appendix - 1).

Muscle Cross Sectional Area Assessment

The cross sectional area of the biceps brachii and the rectus femoris were determined using a diagnostic ultrasound protocol. The ATL ESP Ultrasound Mark 9 (Bothell, WA) with an ATL Curved Linear C7-4 Transducer (Bothell, WA) were used following the manufacturer's protocol for the evaluation of superficial soft tissue structures. The specific settings for resolution and clarity were determined by the sonographer and recorded for each participant to be used for subsequent evaluations. The same sonographer was employed for all testing sessions. The evaluation sites used for both the biceps brachii and rectus femoris were the same silver nitrate marked sites used for the girth measurements. The ultrasound procedure was completed by a sonographer before any of the other exercise testing was done. The participants were placed in a supine position with their extremities positioned for comfort and relaxation. A towel roll supported the knees in a slightly flexed position, while the arm was supported with the shoulders in 80 degrees of abduction and the elbow flexed (see Figures 3-1 and 3-2). Two 5 cm strips of white athletic tape (echo reflective) were placed 1 cm on either side of the evaluation mark in a circumferential direction to help the sonographer locate the test site. The transducer was placed perpendicular to the longitudinal axis of the extremity. Once an ideal image was obtained, the image was frozen on the screen and the sonographer followed the cross sectional area calculation procedure using the track ball and the screen curser. The sonographer used the track ball to trace around the perimeter of the muscle image following the inner edge of the fibrous sheath. The brachial neurovascular bundle was not included in the measurement of the biceps brachii. Both real time video and film copies of the procedure were obtained. This procedure of transducer placement and cross sectional area determination

Figure 3-1. Upper extremity ultrasound positioning diagram. [a] Denotes where the proximal adhesive tape strip was placed. [b] Denotes the silver nitrate location mark where the ultrasound evaluation took place.

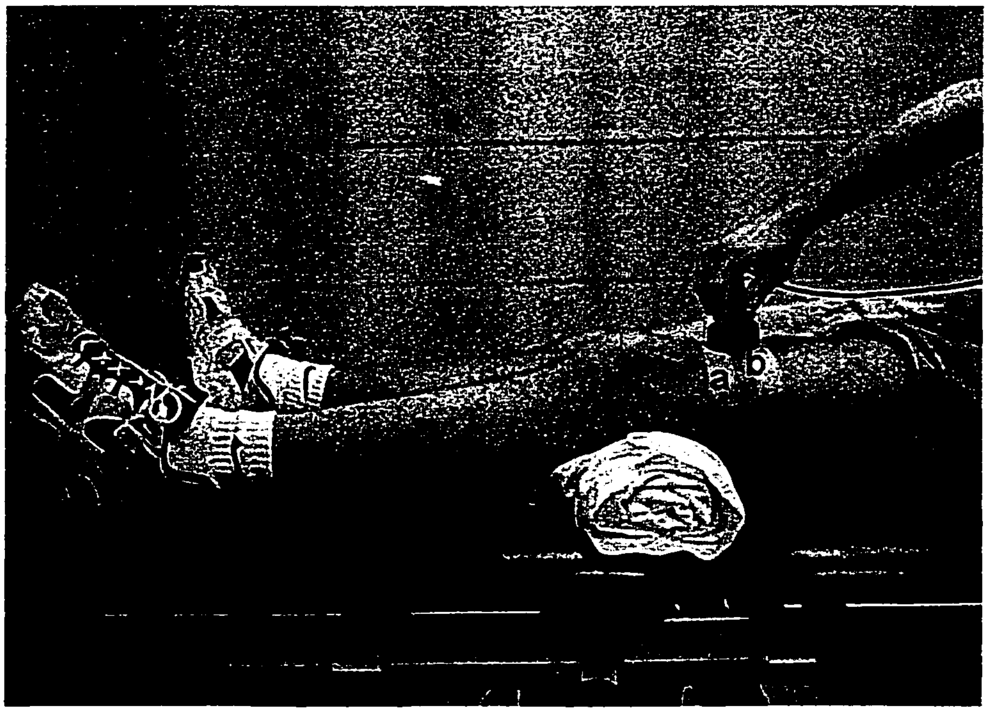

Figure 3-2. Lower extremity ultrasound positioning diagram. [a] Denotes where the proximal adhesive tape strip was placed. [b] Denotes the silver nitrate location mark where the ultrasound evaluation took place.

was completed three times and the average measurement was recorded for later analysis. Both the reliability and the validity of this measurement technique have been documented by several researchers (e.g., Heckmatt, Pier, & Dubowitz, 1988a, 1988b; Hicks, Shawker, Jones, Linzer, & Gerber, 1984; Sipila & Suominen, 1991; Young, Stokes, Round, & Edwards, 1983). The pilot study conducted by the author found both intra-tester and inter- tester reliability to be high. Intraclass Correlation Coefficients of > .98 were found for both intra [Model 3, single rating] and inter [Model 2, mean rating] tester conditions (see Appendix - 2).

The author also completed a reliability and validity study of diagnostic ultrasound in measuring muscle cross sectional area and using magnetic resonance imaging (MRI) as the "gold standard." Twenty able-bodied individuals' bilateral biceps brachii and rectus femoris muscles were evaluated using one magnetic resonance imaging (MRI) evaluation and six ultrasound evaluations (two sonographers x three independent measurements each). The results demonstrate ICC [Model 2, mean rating] ≥ . 93 (see Appendix - 2).

Blood and Urine Collection

Qualified personnel obtained a venous blood sample (10.0 ml) from the antecubital vein. Blood was drawn into a serum-separating vacutainer tube and placed on ice. To maximize the stability of the hormone concentrations in the blood samples, all sampling was completed between 4 p.m. and 6 p.m. (Bell et al., 1997; Hoffman, 1992). Appropriate biohazard precautions were maintained. The blood sampling procedure occurred after 4 p.m. due to the diurnal nature of testosterone. Research has shown that even though serum concentrations tend to be the greatest in the morning, the relatively lower late afternoon concentration tends to be less variable from day to day (Deschenes et al., 1991). Once the blood sample was obtained it was allowed to clot (15 -20 min), then centrifuged (10 min at 3000 x g), after which 1.0 ml of serum was removed for the creatine kinase analysis. The remainder of the serum sample was divided into 4 x 1.0 ml aliquots and frozen at -80° C for the hormone analyses at the conclusion of the study. The multiple aliquots of serum eliminated the need for repeated freezing and thawing of the serum samples for each separate hormone analysis.

During the 24 hours before the testing sessions each individual participated in a cumulative urine collection. The entire 24-hour volume was measured and 2 aliquots of 2.5 ml each were removed and frozen at -80° C for cortisol analysis at the conclusion of the study. The need for a 24-hour collection was due to the variable nature of cortisol that is released into the urine (Bell et al., 1997; Neary et al., 1994).

All participants refrained from exercise for at least 48 hours prior to the 24 hour urine collection and blood collection procedures. The blood sampling procedure was adjusted as necessary to ensure that it occurred outside of the three days before and three days after the peak day of the female participants' menstrual cycle, as described by the manufacturer's instructions (Immuno-Corp, Montreal).

Training Programs

Strength Training Group

The participants in the S group attended three training sessions per week (Monday, Wednesday, and Friday). During each training session they completed the following eight exercises: chest press, pullover, rowing, biceps curl, triceps extension, knee extensions, hamstring curls, and leg press. All exercises except the leg press were performed on Nautilus strength training equipment. The leg press was performed on a generic 45 degree incline plate loaded machine. The wheelchair users did not participate in the three lower extremity exercises. If a participant was unable to move actively through their full range of motion with any given exercise set at the minimum resistance, the supervising staff provided the necessary assistance to complete the movement. To take into account the participants specific functional abilities the resistance used was based on each individual's estimated 1RM from the eight repetition maximum (8RM) exercise specific trials. The estimated 1RM was calculated using a computer software package (Strength Disk, B. E. Software, Lincoln, NE). The estimated 1RM was re-established from an 8RM attempt every two weeks to ensure that the individualized exercise programs provided a progressively overloaded strength training stimulus (Sale, 1987). For each participant's resistance training session, volume and intensity were designed using the Strength Disk computer software package. An increase of 3% in the mean training volume (load x repetitions) was made during weeks 2, 4, 8, and 10, along with a corresponding increase in the weekly average intensity relative to the participant's 1RM. The weekly average intensity started at 70% and increased progressively to 83% over the 12 week training program (Table 3-4). There were also biweekly increases in the number of sets attempted and a corresponding decrease in the number of repetitions performed per set. This program followed the periodized concept, in that within each week a minicycle was created. Mondays and Wednesdays were designed

Table 3-4

Average Weekly Strength Training Intensities Used by the Strength and Combined Strength and Endurance Training Groups

Weeks	Average Intensity (% of 1RM)
1 through 2	70.0[a]
3 through 4	72.5[b]
5 through 6	74.6[b]
7 through 8	75.6[c]
9 through 10	79.7[b]
11 through 12	83.1[b]

Note. [a] Actual 1RM from the pre test. [b] Predicted 1RM from the 8RM test. [c] Actual 1RM from mid test. Range of repetitions were from 2 to 10. Range of sets were from 3 to 6.

to be the highest intensity training days and on Fridays the intensity was decreased slightly (Field, 1988; Millard, 1987). Each training session was supervised and the participants' workouts were recorded on their personalized workout sheet. The program was designed to maximize each individual's neuromuscular and hypertrophic responses to strength training given their overall novice status.

Endurance Training Group

The participants in the E group attended three training sessions per week (Monday, Wednesday and Friday). Table 3-5 presents the outline of the endurance training program. The ambulatory participants used Monark 818 (Monark Stiga, Sweden) cycle ergometers and the wheelchair users used a Monark Arm Crank (Monark Stiga, Sweden) ergometer (the Isokinetic Upper Body Exerciser was used for the testing procedures only). The arm ergometer was modified so that the resistance to the fly wheel was applied via a weight basket hanging under the table that replaced the spring tension adjustment. In the pilot work, it was discovered that this ergometer design was the most reliable in terms of maintaining the desired power output. Each training session was supervised.

Actual performance (time & W) and heart rates (Polar Favor Heart Rate Monitor, Polar Electro Inc, Sweden) were recorded on the individualized training sheets.

On Mondays and Fridays each participant performed continuous aerobic

Table 3-5

Weekly Endurance Training Progressions Used by the Endurance and Combined Strength and Endurance Training Groups

Week	Continuous Training (min:sec)	Power Output (W[c])	Interval Training (sets)	Power Output (W[c])
		Pre-Test		
1	15:00	set from Pre-Test	6	set from Pre-Test
2	16:30		7	
3	18:00		8	
4	18:00	increase 5% - 10%[a]	8	increase 5% - 10%[a]
5	19:45		9	
		Mid-Test		
7	19:45	re-set from Mid-Test	9	re-set from Mid-Test
8	21:40		10	
9	23:50		11	
10	23:50	increase 5% - 10%[b]	11	increase 5% - 10%[b]
11	26:15		12	
12	28:50		13	
		Post-Test		

Note. [a] The power output was adjusted such that the exercise heart rate was maintained at the pre-test training level. [b] The power output was adjusted such that the exercise heart rate was maintained at the mid-test training level. [c] W = Watts

exercise on an ergometer (ambulators used a cycle ergometer and wheelchair users used an arm crank ergometer), at a cadence of 50 rpm and at the resistance and HR equivalent to the power output at VT2 during their $\dot{V}O_{2\,peak}$

pre-test. The duration for the continuous sessions was increased by 10% per week. Each continuous exercise session initially lasted 15 minutes and was progressed to 29 minutes over the course of the 12 week training program. On weeks 4 and 10, the duration remained constant and the power output was increased by 5% to 10% (rounded to the nearest 12.5 W) in order to maintain the participants' target HR. On week 7 the duration was maintained and the resistance was adjusted to match the mid-test power output at VT2 value.

On Wednesdays, the participants completed an interval protocol (90 s work : 90 s rest - minimal resistance) at 50 rpm and at a resistance that represented the resistance half way between the participants' power output at VT2 and their power output at $\dot{V}O_{2\,peak}$. Each Wednesday the number of hard/easy intervals was increased by 1, so the initial 6 sets progressed to 13 by the end of the study. On weeks 4 and 10, the number of sets remained constant and the resistance was increased by 5% (rounded to the nearest 12.5 W). On week 7 the number of sets remained at nine and the resistance was adjusted to match the new resistance value half way between the participants' power output at VT2 and power output at $\dot{V}O_{2\,peak}$ from the mid-study performance testing. This program was designed to maximize the individual's cardiovascular and physiological responses to aerobic training given the participants low initial fitness status and the moderate intensity nature of the program.

Combined Training Group

The participants in the S&E group followed both the S and E group training protocols, training five times per week. Mondays and Wednesdays were strength training days, Tuesdays and Thursdays were endurance training days. On Fridays the participants completed both the strength and endurance training programs. The continuous endurance training protocol was followed on Tuesdays and Fridays. The interval endurance training regime was followed on Thursdays. To ensure an unbiased training effort, the participants alternated the exercise mode (strength or endurance) with which they started each Friday. On Fridays the participants were required to take a minimum break of 30 minutes between the two training sessions.

Biochemical Analyses

All biochemical procedures were performed in the biochemical laboratory at the Faculty of Physical Education and Recreation, University of Alberta. Each participant's complete set of samples were analysed within a single assay to eliminate the possibility of inter-assay variability. All hormones were evaluated by the radio-immunoassay method and were measured in duplicate, and specific procedures were followed as per the suppliers instructions (Immuno-Corp, Montreal). The hormones evaluated included the following: total serum testosterone (Serum Method, Coat-A Count®, TKTT2), urinary free cortisol (Urinary Method, Coat-A Count®, TKCO2), and sex hormone binding globulin

(Monoclonal Anti-SHBG Antibodies, IRMA-Count®, RKSH1). The acceptable coefficient of variation (Portney & Watkins, p. 646, 1993) upper limit for the hormone determinations was set by the researcher at 20%. Table 3-6 documents the range of coefficient of variations and the number of matched samples that were eliminated from further analyses.

Table 3-6

Coefficients of Variation for the Hormone Analyses

	Intra-assay Precision (CV)[a]	Total number of duplicates performed	Number of duplicates were CV [b] > 20%
Cortisol	2.5%	101	18
Sex Hormone Binding Globulin	2.8% - 3.6%	97	16
Testosterone	5.0%	97	3

Note: [a] Mean values provided by the manufacturer. [b] Coefficient of Variation (CV).

Creatine kinase was analysed using the standard spectrophotometric methodology as described by Hess, Macdonald, Natho, and Murdock (1967) and Rosalki, (1967) The 1.0 ml aliquot of serum allocated for the creatine kinase determinations was immediately refrigerated and the analyses were performed within 10 hours of the blood sampling procedure (Hess et al., 1967; Rosalki 1967). All creatine kinase determinations were done in duplicate. Using this criteria, of the 85 creatine kinase determinations performed, 15 were discarded from further analysis due to coefficients of variation that were greater than 20%.

Statistical Analyses

Data were analysed to determine whether an interference effect was present between the strength and endurance adaptations in the S&E training group. In addition, the physiological responses and adaptations to muscular strength training and aerobic endurance training were examined separately. Figure 3-3 presents a flow-chart for the statistical analysis strategy used in this study.

Due to the nature of the sample used in this study and disability specific heterogeneity of the participants within the groups, an analysis of person by treatment interaction (PTI) was completed for each of the dependent variables. Individuals in any group, no matter how homogeneous, may not respond identically to a given training regimen (Bouffard, 1993). As an example, Bouffard cites a study by Lortie et al. (1984) which found that after a 20 week cycle ergometry endurance training program the improvement in $\dot{V}O_{2\,max}$ ranged from 5 to 88% for their 24 participants. This variable response to the same stimuli is called a PTI. In the exercise literature the participants' scores are often aggregated and the mean of their scores analysed. The risk of not evaluating for the presence of PTI variations is that potentially important information on the individual's response is lost. In addition, if a PTI exists then the ability to generalize from the sample aggregate to people would be threatened (Bouffard, 1993). The detection of a PTI for any given dependent variable does not

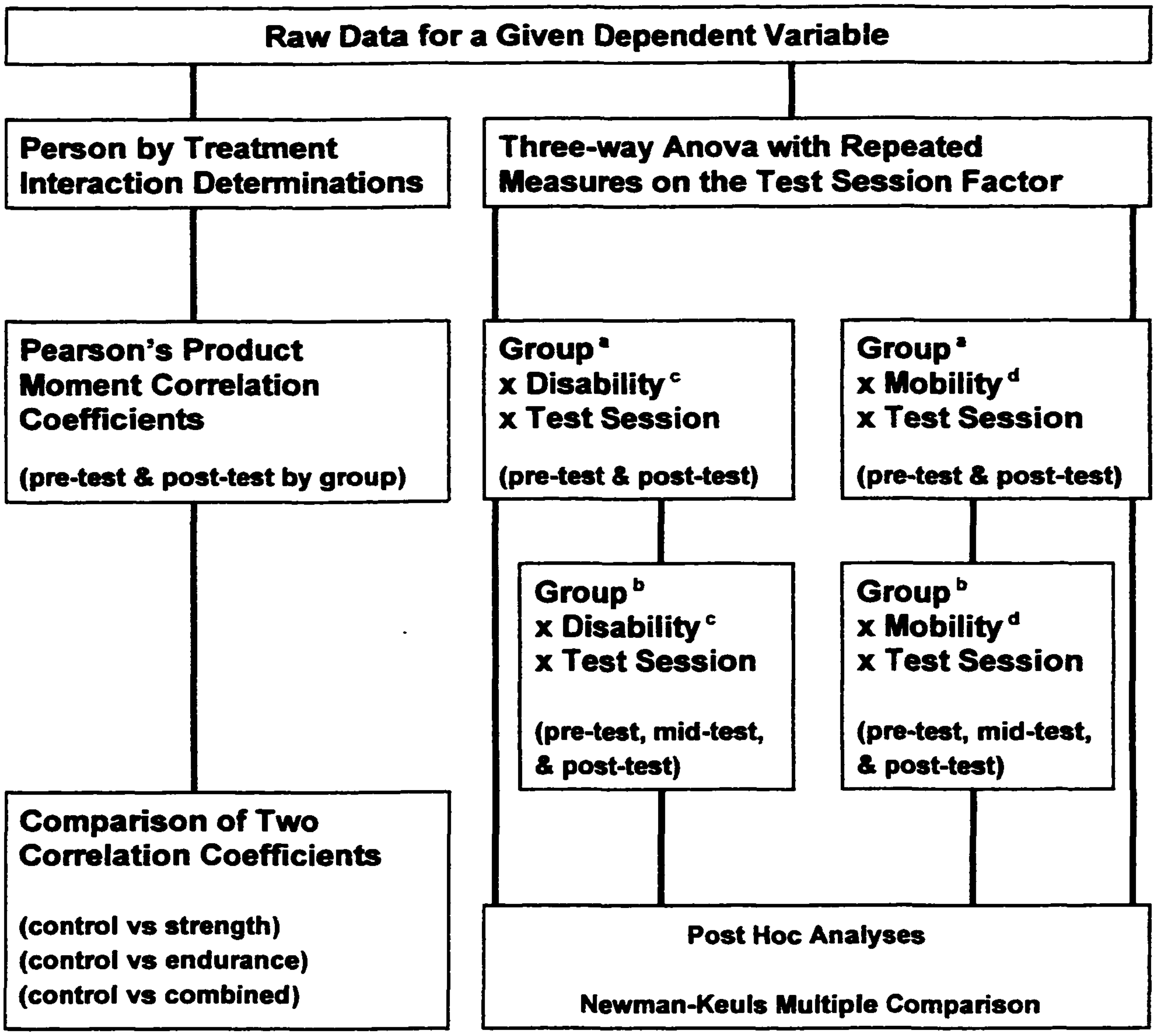

Figure 3-3. Flow chart of the statistical analyses procedures. [a] These analyses used all four experimental groups. [b] These analyses used only the three exercise groups (the control group was not included in during the mid-test data collection). [c] The disability factor is comprised of three levels; SCL, CP/HI, and MS. [d] The mobility factor is comprised of two levels; ambulatory and wheelchair users.

preclude the use of ANOVA results, but helps to explain a portion of the variance between participants. Bouffard (personal communication M. Bouffard, July 3, 1997) suggested that the methodology discussed in his 1993 article (subtitled "Evidence Based on Correlation Coefficients") would be acceptable for this study. Pearson Product-Moment Correlation Coefficients (r) were calculated for each of the four study groups for each of the dependent variables, using the pre and post-test values. It was assumed that any changes in a given dependent variable in the C group would reflect the normal variation in that variable when observed over the 12 week training period. The normal variation of the participants in the C group acts as a baseline for comparison of the participants in the three training groups. Therefore, the r statistics from the C group for each dependent variable were tested against each of the three training group's correlation coefficients. A PTI was considered present if a training group's correlation coefficient was significantly lower than the C group's. The test used for comparing two correlation coefficients was described by Zar (1984, p. 313).

The null hypotheses about means for each dependent variable was tested with a three-way ANOVA with one repeated measure (test sessions). StatSoft™ discusses in their technical notes (p. 1635, 1994) that the ANOVA/MANOVA program implements the general linear model as described by Finn (1974, 1977). Overall and Spiegel (1969) demonstrated that there was an inherent risk from the arbitrary use of any one of the several least squares methods that are available for use with an unbalanced experimental design. Method 1, a regression approach, "adjusts each effect for all other effects in the design to obtain its unique contribution" (Stevens, p. 294, 1996). The STATISTICA program by StatSoft™ defaults to Method 1 regression approach as described above whenever unequal cell sizes are encountered while performing ANOVA/MANOVA analyses.

As depicted in Figure 3-3, the intended sequence of three-way ANOVAs with repeated measures on the last factor were as follows: Training Group x Disability Type x Test Session and Training Group x Mode of Mobility x Test Session. Disability type refers to the three previously defined medical disability groups; SCL, CP/HI, and MS. The mode of mobility refers to whether the participants were ambulatory or wheelchair users. Unfortunately, the Training Group x Disability Type x Test Session three-way ANOVA with repeated measures on the Test Session factor was not performed. The choice to eliminate this procedure from the statistical analysis procedure was a result of the small sample size used in this study, a number of the cells contained a $\underline{n} < 2$. Therefore, using Disability Type as a factor was deemed inappropriate (Portney & Watkins, 1993) . Thus, only the three-way ANOVA with repeated measures on the last factor (Training Group x Mode of Mobility x Test Session) was performed in this study.

The initial three-way ANOVA with repeated measures on the last factor (Training Group x Mode of Mobility x Test Session) of each dependent variable used a Training Group factor which included all four experimental groups and a Test Session factor which included only the pre-test and post-test data. A Newman-Keuls multiple comparisons procedure was used for the post hoc analyses of any significant interaction. If there was a significant two-way

Training Group x Test Session interaction a second three-way ANOVA (Training Group x Mode of Mobility x Test Session) with repeated measures on the last factor was performed. This second analysis used a Training Group factor which included only the three experimental training groups and a Test Session factor which included all three testing sessions. The C group was excluded because they were not included in the mid-test data collection. This second three-way ANOVA was performed specifically to observe if the rate or magnitude of change varied between three exercise groups and the first and second halves of the study. A Newman-Keuls multiple comparisons procedure was used for the post hoc analyses of any significant interaction.

Analysis of variance models including more than three factors, and multivariate analysis procedures, were not attempted due to the small sample sizes of the four study groups (Portney & Watkins, 1993). Alpha was set at $\underline{p} \leq .05$. STATISTICA for Windows (Statsoft, Tulsa, OK) was the software package used for all statistical operations.

CHAPTER IV
RESULTS

Thirty-six of the thirty-seven of the participants attended and completed all of the required training sessions. Three participants missed two training sessions however, only one of the three was unable to make up the missed training sessions. All but five participants attended all of the required physiological testing sessions and successfully completed all of the testing. One participant refused to participate in the blood acquisition procedures and two others were unable to make up missed venipuncture appointments. Therefore, their endocrine data was not used in the data analyses.

Person by Treatment Interaction

As discussed in Chapter III if all members of a group respond similarly to an intervention, then generalizing from the aggregate to people may be warranted. However, if the members of a group respond to a treatment in a dissimilar manner, then the group mean will not capture this varied response.

Table 4-1 presents the results of the PTI analyses from this study. A significant PTI, at the $\underline{p} \leq .05$ level was found for $\dot{V}O_{2\,peak}$ and power output at $\dot{V}O_{2\,peak}$ for the S&E group. Thus individuals in the S&E group responded differentially to the intervention, but this was not the case for any of the other training groups when aerobic endurance was assessed. The PTI within the S&E

Table 4-1

Person by Treatment Interaction Analysis (Z values) for each Dependent Variable Comparing the Control Group to the Strength Training (S), Endurance Training (E), and the Combined Strength and Endurance Training (S&E), Groups

Dependent Variable	S	E	S&E
Body Mass	0.46	0.82	0.65
Skinfolds - sum of 3	1.04	1.66	1.07
1RM - UE	0.28	0.16	0.90
1RM - LE	0.09	0.97	1.18
$\dot{V}O_2$ at VT2	0.06	1.15	0.37
$\dot{V}O_{2\,peak}$	0.70	0.63	1.98*
PO at VT2	0.29	0.44	1.42
PO at $\dot{V}O_{2\,peak}$	0.03	0.60	1.97*
Creatine Kinase	1.72	1.53	1.76
Serum Total Testosterone	0.37	0.52	0.63
Urinary Free Cortisol	0.92	1.43	0.68
Sex Hormone Binding Globulin	0.51	1.02	0.72
Ultrasound - arms	1.06	1.84	1.31
Ultrasound - legs	0.23	1.43	1.33

Note: [a] Calculated as described in Biostatistical Analysis (2nd ed.). by J. H. Zar, 1984, Englewood Cliffs, NJ: Prentice-Hall, Inc. p, 313. * Significant PTI - critical value for $\underline{Z}_{0.05(2)} = \underline{t}_{0.05(2)}, \infty = 1.96$.

group for the $\dot{V}O_{2\,peak}$ and power output at $\dot{V}O_{2\,peak}$ measurements were eliminated when the data were re-examined separating participants who used an arm crank ergometer from participants who used the cycle ergometer. It appears that the PTI resulted from a differential response between participants who arm cranked and participants who leg cycled.

Body Composition

The three-way, Training Group x Mode of Mobility x Test Session ANOVA, with repeated measures on the Test Session factor, found no significant differences in the participants' body composition or body mass across groups over time (Tables A5-1 and A5-2 respectively). The groups' mean and standard error of the mean for the analyses are presented in Tables 4-2 and 4-3. Of the 37 participants, 2 were considerably obese and 2 were unable to relax their upper extremity muscles, so that reproducible skinfold measures were impossible to obtain. Mid-test values were not collected for any of the groups because it was not possible to secure the same person to carry out these measurements.

Strength

Elbow Flexors

All 37 participants completed the UE 1RM strength assessment. These data were first examined by a three-way (Training Group x Mode of Mobility x

Table 4-2

Mode of Mobility Sub Group by Test Session Means for the Strength (S), Endurance (E), Combined Strength and Endurance (S&E), and the Control (C) Groups' Sum of Three Skinfolds Measurements[a] (mm)

Group	Mode of Mobility	n	Pre-test	Post-test
S	L/E[b]	4	78.63 ± 20.89	66.00 ± 16.13
	U//E[c]	4	35.40 ± 7.87	34.98 ± 8.03
E	L/E	4	63.30 ± 2.40	66.85 ± 6.05
	U/E	4	79.18 ± 9.49	72.00 ± 10.59
S&E	L/E	6	65.84 ± 10.48	61.82 ± 11.54
	U/E	2	61.55 ± 24.09	59.43 ± 24.47
C	L/E	4	64.40 ± 11.81	67.99 ± 13.82
	U/E	5	74.44 ± 23.80	70.42 ± 21.63

Note. The values represent the group mean ± standard error of the mean. [a] The sum of three skinfold measurements were comprised of the following sites: biceps, triceps, and subscapular. [b] Ambulatory. [c] Wheelchair user.

Table 4-3

Mode of Mobility Sub Group by Test Session Means for the Strength (S), Endurance (E), Combined Strength and Endurance (S&E), and the Control (C) Groups' Body Mass Measurements (kg)

Group	Mode of Mobility	n	Pre-test	Post-test
S	L/E[a]	4	79.38 ± 10.91	79.10 ± 11.00
	U/E[b]	6	63.33 ± 8.00	62.45 ± 7.29
E	L/E	4	81.30 ± 5.85	82.60 ± 6.00
	U/E	6	70.20 ± 5.07	70.88 ± 5.19
S&E	L/E	6	71.55 ± 6.21	71.43 ± 6.51
	U/E	2	74.55 ± 8.64	74.50 ± 8.19
C	L/E	4	78.78 ± 14.83	79.48 ± 14.71
	U/E	5	69.00 ± 11.64	68.78 ± 11.01

Note. The values represent the group mean ± standard error of the mean [a] Ambulatory.
[b] Wheelchair user.

Test Session) ANOVA with repeated measures on the Test Session factor. The primary ANOVA procedure used the data from all four experimental groups (S, E, S&E, and C) from the pre and post-testing sessions. A second ANOVA procedure, which omitted the C group and included the mid-test data for the three training groups, was performed if the two-way interaction (Training Group x Test Session) was significant.

The results of the three-way (Training Group x Mode of Mobility x Test Session) ANOVA with repeated measures on the Test Session factor presented in Table A5-3 revealed three significant two-way interactions. Table 4-4 displays the group means and standard errors of the mean. Post hoc analyses (Newman-Keuls multiple comparison) of the significant interaction between Mode of Mobility and Test Session (F (1, 29) = 10.10, p = .005) showed that the wheelchair users in this study were significantly stronger than those who ambulated at the time of pre and post-testing (p = .0001 and p = .0001 respectively). The wheelchair users significantly increased their upper extremity strength between the pre and post-test sessions (p = .0001). Daily wheelchair use appeared to enhance the development of elbow flexor strength.

As noted above the two-way (Training Group x Mode of Mobility) interaction was significant (F (3, 29) = 3.14, p = .040). Post hoc analysis demonstrated that the wheelchair users in the SE groups had significantly (p = .047) greater elbow flexor strength than the wheelchair users in the C group.

Training Group x Test Session was the third significant interaction F (3, 33) = 3.76, (p = .02) found in the initial three-way ANOVA with the Test Session as the repeated factor. Table 4-4 gives the groups' mean and standard error of the mean for this significant interaction. Post hoc examination (Newman-Keuls) showed that both the S (p = .0004) and S&E (p = .001) groups significantly improved over the duration of the study. However, there was no significant difference between these two training groups at the end of the 12 weeks (S versus S&E, p = .323). The S and S&E groups' elbow flexion strength, although

Table 4-4

Training Group by Test Session Means for the Strength (S), Endurance (E), Combined Strength and Endurance (S&E), and the Control (C) Groups' Bilateral Elbow Flexor 1RM Strength (kg)

Group	n	Pre-test	Mid-test	Post-test
S	10	23.0 ± 3.7	27.0 ± 4.5	30.8 ± 4.9 *
E	10	20.9 ± 4.4	22.4 ± 4.8	21.8 ± 4.2 †
S&E	8	22.2 ± 3.7	26.0 ± 4.8	29.0 ± 4.8 *
C	9	15.5 ± 3.8 **	n/a	17.9 ± 4.2 †

Note. The values represent the group mean ± standard error of the mean. * Denotes a significant difference between the pre and post-tests. † Denotes a significant difference from the S and S&E groups after 12 weeks of training. ** Denotes a significant difference from the S, E, and S&E groups at the time of pre-testing.

not significantly different from the E group's at the onset of the study, were significantly greater than the E group's elbow flexion strength by the conclusion of the study (p = .0003 and p = .006 respectively). The C group concluded the study with no significant changes in their elbow flexor strength (p = .190). However at the onset of the study the C group demonstrated elbow flexor 1RM values that were significantly less than the S (p = .002), E (p = .013), and the S&E (p = .005) groups'. By the conclusion of the study, both the C and E groups' elbow flexor strength values were not significantly (p =.083) different.

Because there was a significant Training Group x Test Session interaction the second three-way ANOVA with repeated measures on the Test Session factor was completed. The purpose of this analysis was to observe if the rate or magnitude of change varied between three exercise groups and the first and second halves of the study. To accomplish this goal the three experimental exercise groups were evaluated across all three testing sessions.

The addition of the mid-test data and the exclusion of the C group in the two-way (Training Group x Test Session) ANOVA with repeated measures on the last factor (Table A5-4), also revealed a significant Training Group x Test Session interaction, F (4, 42) = 6.05, p = .02. Of the 28 participants in the three training groups, one participant from the E group was unable to participate in the mid-strength testing session. Post hoc analysis showed a significant increase in pre to post-test strength for both the S and the S&E groups (p = .0002 and p = .002, respectively). There was no significant differential response between the two halves of this study for either the S or the S&E groups.

Post hoc analyses of the significant interaction between Mode of Mobility and Test Session (F (2, 42) = 10.19, p = .016) showed that the wheelchair users were stronger overall, and their strength increased significantly between the mid and pre-test sessions (p = .0001) as well as between post and mid-test sessions (p = .0001).

Knee Extensors

Table 4-5 presents the groups' mean and standard error of the mean for the knee extensor 1RM evaluations. Of the 37 participants in this study only 20 could adequately and safely perform the leg press exercise. This further reduced

Table 4-5

Training Group by Test Session Means for the Strength (S), Endurance (E), Combined Strength and Endurance (S&E), and the Control (C) Groups' Bilateral Knee Extensor 1RM Strength (kg)

Group	n	Pre-test	Mid-test	Post-test
S	4	105.5 ± 27.1	130.3 ± 28.0	150.4 ± 32.3 *
E	3	214.0 ± 15.9 †	220.5 ± 4.0	220.4 ± 10.7
S&E	6	156.1 ± 16.1 ‡	178.2 ± 18.9	200.7 ± 22.2 *
C	7	103.0 ± 20.7	n/a	109.5 ± 23.1

Note. The values represent the group mean ± standard error of the mean. * Denotes significant differences between the pre and post- tests, the pre and mid-tests, and the mid and post-tests.
† Denotes a significant difference from the S, S&E, and C groups at the time of pre-testing.
‡ Denotes a significant difference from the S and C groups at the time of pre-testing.

the sample size which resulted in the inability to perform any of the planned three-way ANOVAs. Therefore, the analyses for this dependent variable began with the two-way (Training Group x Test Session) ANOVA with repeated measures on the Test Session factor.

The two-way (Training Group x Test Session) ANOVA with repeated measures on the last factor (pre and post-test sessions) for all four experimental groups (S, E, S&E, and C) presented in Table A5-5 revealed a significant Training Group x Test Session interaction, F (3, 16) = 7.00, p = .003. The Training Group x Test Session interaction was also found to be significant (F (4, 20) = 2.91, p = .048) when the data were analyzed after the C group was eliminated from the calculation and using the measurements from the pre, mid, and post-test sessions (Table A5-6). Though post hoc analysis showed that the E group had a significantly higher mean pre-experiment value as compared to the S, S&E, and C groups (p = .0002, .0002, and .0002 respectively) there were no significant changes in this group's knee extensor strength throughout the course of the study (p = .986). The Newman-Keuls multiple comparison post hoc analysis showed that the S&E group was significantly stronger (p = .0003) than the S group prior to the onset of training, and this remained true at the conclusion (p = .0001). Post hoc analysis revealed that both the S (p = .0002) and S&E (p = .0003) groups significantly increased their knee extensor strength over the course of the 12 weeks of training. Furthermore, the post hoc analysis demonstrated significant knee extensor strength gains during both halves of the study for both the S and S&E groups (pre-test to mid-test p = .009 and p = .030 respectively; mid-test to post-test p = .018 and p = .017 respectively).

Oxygen Consumption

Of the 37 participants in this study, 3 did not complete the post-test session (1 from the E group and 2 from the C group). Therefore the data from these participants were not included in the following analyses of $\dot{V}O_2$.

Peak Oxygen Consumption

Table 4-6 presents the Mode of Mobility sub groups' mean and standard

Table 4-6

Mode of Mobility Sub Group by Test Session Means for the Strength (S), Endurance (E), Combined Strength and Endurance (S&E), and the Control (C) Groups' Peak Oxygen Consumption (L/min)

Group	Mode of Mobility	n	Pre-test	Mid-test	Post-test
S	L/E[a]	6	1.77 ± 0.29	1.74 ± 0.28	1.84 ± 0.30
	U/E[b]	4	1.65 ± 0.26	1.48 ± 0.25	1.34± 0.24
E	L/E	3	2.37 ± 0.24	2.39 ± 0.29	2.21 ± 0.27
	U/E	6	1.39 ± 0.31	1.42 ± 0.33	1.48 ± 0.34
S&E	L/E	5	2.48 ± 0.16	2.34 ± 0.18	2.00 ± 0.10
	U/E	3	2.15 ± 0.16	2.31 ± 0.09	2.31 ± 0.07
C	L/E	4	1.81 ± 0.22	n/a	1.67 ± 0.22
	U/E	3	1.14 ± 0.23	n/a	1.09 ± 0.25

Note. The values represent the group mean ± standard error of the mean. [a] Ambulatory. [b] Wheelchair user. The L/E group as a whole demonstrated a significant decrease in $\dot{V}O_{2\,peak}$ between the pre and post-test sessions (p = .0003).

error of the mean for $\dot{V}O_{2\,peak}$. The three-way (Training Group x Mode of Mobility x Test Session) ANOVA with repeated measures on the Test Session factor (Table A5-7) revealed a significant Mode of Mobility x Test Session interaction (F (1, 26) = 16.35, p = .0004). Overall the ambulatory participants tested on the cycle ergometer had significantly greater $\dot{V}O_{2\,peak}$ values as compared to the wheelchair users who performed the testing protocol on an arm ergometer. Post hoc analyses also indicated that there were no significant improvements in $\dot{V}O_2$

$_{peak}$ after the 12 weeks of aerobic endurance training in any of the training groups. In fact the ambulatory participants, who were tested on the leg cycle ergometer, actually demonstrated a significant decrease in $\dot{V}O_{2\,peak}$ between the pre and post-test sessions ($\underline{p}$ = .0003).

Oxygen Consumption at the Second Ventilatory Threshold

The three-way (Training Group x Mode of Mobility x Test Session) ANOVA with repeated measures on the Test Session factor (Table A5-8), revealed no significant interactions. There was a significant main effect of the Mode of Mobility when the data were examined with all four groups (S, E, S&E, and C) and the pre-to-post data ($\underline{F}$ (1, 26) = 4.51, $\underline{p}$ = .043). Post hoc evaluation showed that participants who performed the tests using cycle ergometry had significantly greater $\dot{V}O_2$ values at VT2 than participants who performed arm ergometry. Table 4-7 gives the Mode of Mobility sub groups' mean and standard error of the mean for VO_2 at VT2.

Percentage of Peak Oxygen Consumption at Which the Second Ventilatory Threshold Occurred

The average percentage of $\dot{V}O_{2\,peak}$ at which VT2 occurred for each of the four study groups and subdivided by mode of mobility presented in Table 4-8. The three-way (Training Group x Mode of Mobility x Test Session) ANOVA with

Table 4-7

Mode of Mobility Group by Test Session Means for the Strength (S), Endurance (E), Combined Strength and Endurance (S&E), and the Control (C) Groups' Oxygen Consumption (L/min) at the Second Ventilatory Threshold

Group	Mode of Mobility	n	Pre-test	Mid-test	Post-test
S	L/E[a]	6	1.29 ± 0.19	1.30 ± 0.26	1.19 ± 0.27
	U/E[b]	4	1.13 ± 0.18	1.16 ± 0.15	1.23 ± 0.20
E	L/E	3	1.56 ± 0.03	1.70 ± 0.15	1.72 ± 0.13
	U/E	6	0.91 ± 0.18	0.98 ± 0.14	1.05 ± 0.20
S&E	L/E	5	1.34 ± 0.15	1.60 ± 0.13	1.41 ± 0.08
	U/E	3	1.35 ± 0.25	1.22 ± 0.01	1.36 ± 0.07
C	L/E	4	1.23 ± 0.16	n/a	1.25 ± 0.14
	U/E	3	0.83 ± 0.22	n/a	0.71 ± 0.06

Note. The values represent the group mean ± standard error of the mean. [a] Ambulatory. [b] Wheelchair user. As a cohort the L/E demonstrated significantly greater VO_2 at VT2 as compared to the U/E.

repeated measures on the Test Session factor did not reveal any significant changes in the percentage of $\dot{V}O_{2\,peak}$ that VT2 occurred after 12 weeks of training.

Table 4-8

Average Percentage of Peak Oxygen Consumption at Which the Second Ventilatory Threshold Occurred by Mode of Mobility for the Strength (S), Endurance (E), Combined Strength and Endurance (S&E), and the Control (C) Groups'

Group	Mode of Mobility	n	Pre-test	Mid-test	Post-test
S	L/E[a]	4	78.2	87.8	88.8
	U/E[b]	6	63.8	66.7	66.8
E	L/E	3	65.8	71.1	77.8
	U/E	6	65.5	69.0	71.0
S&E	L/E	6	54.0	68.4	70.5
	U/E	2	62.8	52.8	58.9
C	L/E	5	68.0	n/a	74.9
	U/E	2	72.8	n/a	65.1

Note. The values calculated as ($\dot{V}O_2$ at VT2/$\dot{V}O_{2\,peak}$)x100 . [a] Ambulatory. [b] Wheelchair user.

Power Output

Of the 37 participants in this study, 3 did not complete the post-test session (1 from the E group and 2 from the C group). In addition, the power outputs at $\dot{V}O_{2\,peak}$ and VT2 could not be accurately assessed in two other participants from the E group. During the mid-testing session the power output at $\dot{V}O_{2\,peak}$ and VT2 were identical. Therefore, their performance data were not included in the following power output analyses.

Power Output at Peak Oxygen Consumption

When the power output at $\dot{V}O_{2\,peak}$ was evaluated using a three-way (Training Group x Mode of Mobility x Test Session) ANOVA with repeated measures on the last factor a significant three-way interaction was found. This significant three-way interaction was revealed in Tables A5-9 (F (3, 24) = 3.85, p = .022). Table 4-9 gives the Mode of Mobility groups' mean and standard error of the mean for power output at $\dot{V}O_{2\,peak}$.

Post hoc analyses of this three-way interaction demonstrated that both the upper extremity endurance (Eu/e) (p = .048) and the upper extremity combined (S&Eu/e) (p = .0002) training groups achieved significant increases in power output at $\dot{V}O_{2\,peak}$ by the end of the experiment. At that time, the increase in the power output by S&Eu/e group was significantly greater (p = .0002) than that achieved by the Eu/e group. Although the wheelchair users in the E and S&E groups significantly increased their power output at $\dot{V}O_{2\,peak}$ the post hoc analyses demonstrated no significant change in the power output at $\dot{V}O_{2\,peak}$ for either the lower extremity endurance (El/e) or the lower extremity combined (S&El/e) groups.

Power output at $\dot{V}O2$ peak was also analyzed using only the three exercising

experimental groups and with the addition of the mid-test data using a three-way ANOVA (Training Group x Mode of Mobility x Test Session) with repeated measures on the Test Session factor. As seen in Table A5-10 a significant

Table 4-9

Mode of Mobility Group by Test Session Means for the Strength (S), Endurance (E), Combined Strength and Endurance (S&E), and the Control (C) Groups' Power Output (W) at Peak Oxygen Consumption

Group	Mode of Mobility	n	Pre-test	Mid-test	Post-test
S	L/E[a]	4	107.9 ± 18.1	125.0 ± 19.3	125.0 ± 19.3
	U/E[b]	6	84.5 ± 18.1	90.2 ± 18.6	90.4 ± 17.6
E	L/E	3	146.5 ± 34.8	164.3 ± 35.7	154.2 ± 30.1
	U/E	4	105.6 ± 28.9	116.3 ± 31.7	132.5 ± 40.5 *
S&E	L/E	6	161.6 ± 14.2	173.3 ± 11.7	171.1 ± 18.5
	U/E	2	120.0 ± 5.1	175.0 ± 0.00	182.5 ± 7.6 **†
C	L/E	5	117.1 ± 20.1	n/a	124.4 ± 26.0
	U/E	2	72.2 ± 16.1	n/a	74.4 ± 19.6

Note. The values represent the group mean ± standard error of the mean. [a] Ambulatory. [b] Wheelchair user. * Denotes a significant difference between the pre and post-tests. ** Denotes significant differences between the pre and post-tests and pre and mid-tests. † Denotes a significant difference between the S&Eu/e and the Eu/e groups at the conclusion of the study.

three-way interaction was found (F (4, 38) = 4.35, p = .005). The post hoc analysis demonstrated similar pre to post-test findings as have been noted previously except for a significant increase in power output between the pre to mid-test period for the S&Eu/e group (p = .0001). This significantly greater increase in power output for the S&Eu/e may demonstrate an enhanced aerobic endurance effect with the addition of a strength training stimulus as compared to endurance training alone.

Power Output at the Second Ventilatory Threshold

A significant Training Group x Test Session interaction was also found for the three-way (Training Group x Mode of Mobility x Test Session) ANOVA with repeated measures on the Test Session factor as presented in Tables A5-11 (F (3, 24) = 11.04, p = .0001). The Mode of Mobility did not appear to play a role in the significant power output gains at VT2 for either the E or S groups.

Post hoc analysis of the significant Training Group x Test Session interaction found significant increases in the power output at VT2 for the S&E (p = .0001) and E (p = .0003) groups over the 12 weeks of training. Although there was no significant difference among groups at the time of the pre-test, both the E (p = .0001 and .0001 respectively) and SE (p = .0002 and .0001 respectively) groups' power output at VT2 were significantly greater than those observed in either the S or C groups' by the end of the study. The S&E group's improvements were significantly greater than that of the E group (p = .008).

With the inclusion of the mid-test data, (see Table A5-12) the post hoc analysis of the Training Group x Test Session interaction showed that the S&E group had significant increases in power output at VT2 between the pre to mid-test (p = .013) and mid to post-test (p = .0005) session intervals. Table 4-10 gives the groups' mean and standard error of the mean for power output at VT2.

Table 4-10

Training Group by Test Session Means for the Strength (S), Endurance (E), Combined Strength and Endurance (S&E), and the Control (C) Groups' Power Output (W) at the Second Ventilatory Threshold

Group	n	Pre-test	Mid-test	Post-test
S	10	75.8 ± 10.5	81.1 ± 9.5	82.6 ± 10.3 **
E	10	86.9 ± 13.9	93.8 ± 12.9	103.1 ± 17.1 *
S&E	8	81.6 ± 5.8	93.3 ± 6.8	113.3 ± 7.8 * † ‡
C	9	68.9 ± 12.1	n/a	71.0 ± 13.1 **

Note. The values represent the group mean ± standard error of the mean. * Denotes a significant difference between the pre and post-tests. † Denotes a significant difference between the pre and mid-tests and mid and post-tests. ** Denotes a significant difference from the ET and SE groups at the time of post-testing. ‡ Denotes a significant difference from the ET group at the time of post-testing.

Heart Rate

Heart Rate at Peak Oxygen Consumption

Table 4-11 presents the mean HR at $\dot{V}O_{2\,peak}$ for the each of the four training groups and by mode of mobility across the three training sessions. The statistical analysis procedures demonstrated that there were no differences in HR at $\dot{V}O_{2\,peak}$ among the training groups or across testing sessions. The average training group HRs obtained at $\dot{V}O_{2\,peak}$ averaged between 85% to 95% of the average age predicted maximal HR. A two-way (Training Group x Test Session) ANOVA with repeated measures on the last factor (pre and post-test

Table 4-11

Training Group and Mode of Mobility by Test Session Means for the Strength (S), Endurance (E), Combined Strength and Endurance (S&E), and the Control (C) Groups' Heart Rate (bpm) at Peak Oxygen Consumption

Group	n	Pre-test	Mid-test	Post-test
S	10	176 ± 21	175 ± 24	176 ± 23
E	7	165 ± 19	167 ± 20	164 ± 22
S&E	8	178 ± 10	178 ± 10	180 ± 9
C	6	158 ± 25	n/a	155 ± 27
All U/E [a]	12	185 ± 14	185 ± 16	184 ± 16
All L/E	19	162 ± 18	164 ± 16	162 ± 21

Note. The values represent the group mean ± standard deviation. [a] Denotes the overall significantly greater HR at $VO_{2\,peak}$ of the U/E exercisers across all three testing sessions.

sessions) was performed and the significant main effect (F (1, 22) = 10.07, p = .004) was found. This main effect demonstrated that the HR achieved at $\dot{V}O_{2\,peak}$ by the wheelchair users was significantly greater than those who were tested on the cycle ergometer.

Heart Rate at the Second Ventilatory Threshold

Table 4-12 presents the mean HR at VT2 for the each of the four training groups and by mode of mobility across the three training sessions. The statistical analysis procedures demonstrated that there were no differences in HR at VT2 among the training groups or across testing sessions. The average training group HRs obtained at VT2 averaged between 72% to 80% of the

Table 4-12

Training Group and Mode of Mobility by Test Session Means for the Strength (S), Endurance (E), Combined Strength and Endurance (S&E), and the Control (C) Groups' Heart Rate (bpm) at the Second Ventilatory Threshold

Group	n	Pre-test	Mid-test	Post-test
S	10	146 ± 20	147 ± 20	150 ± 23
E	7	139 ± 14	134 ± 18	140 ± 19
S&E	8	143 ± 17	142 ± 11	152 ± 16
C	6	136 ± 21	n/a	136 ± 21
All U/E	12	147 ± 20	147 ± 20	150 ± 22
All L/E	19	139 ± 15	137 ± 13	142 ± 19

Note. The values represent the group mean ± standard deviation.

average age predicted maximal HR. There was also no significant difference between the HRs attained by the UE versus the LE exercisers.

Respiratory Exchange Ratio

Respiratory Exchange Ratio at Peak Oxygen Consumption

Table 4-13 presents the mean RER at $\dot{V}O_{2\,peak}$ for the each of the four training groups and by mode of mobility across the three training sessions. The statistical analysis procedures demonstrated that there were no differences in RER at $\dot{V}O_{2\,peak}$ between the training groups or across testing sessions. The

Table 4-13

Training Group and Mode of Mobility by Test Session Means for the Strength (S), Endurance (E), Combined Strength and Endurance (S&E), and the Control (C) Groups' Respiratory Exchange Ratio at Peak Oxygen Consumption

Group	n	Pre-test	Mid-test	Post-test
S	10	1.15 ± 0.10	1.17 ± 0.14	1.14 ± 0.10
E	7	1.14 ± 0.07	1.17 ± 0.07	1.16 ± 0.11
S&E	8	1.12 ± 0.07	1.13 ± 0.12	1.13 ± 0.08
C	6	1.04 ± 0.05	n/a	1.08 ± 0.05
All U/E [a]	12	1.18 ± 0.08	1.24 ± 0.08	1.17 ± 0.08
All L/E	19	1.08 ±0.07	1.09 ± 0.09	1.11 ± 0.09

Note. The values represent the group mean ± standard deviation. [a] Denotes the overall significantly greater RER at $\dot{V}O_{2\,peak}$ of the U/E exercisers across all three testing sessions.

two-way (Training Group x Test Session) ANOVA with repeated measures on the last factor (pre and post-test sessions) found a significant main effect (F (1, 29) = 10.96, p = .003). This main effect showed that the RER calculated at $\dot{V}O_{2\,peak}$ by the wheelchair users was significantly greater than for those who were tested on the cycle ergometer.

Respiratory Exchange Ratio at the Second Ventilatory Threshold

Table 4-14 presents the mean RER at VT2 for the each of the four training groups and by mode of mobility across the three training sessions. A two-way (Training Group x Test Session) ANOVA with repeated measures on the last factor (pre and post-test sessions) demonstrated the mean RER at VT2 for the S&E training group was significantly lower (F (2, 20) = 3.61, p = .046) than for the other training groups across the three testing sessions.

Table 4-14

Training Group and Mode of Mobility by Test Session Means for the Strength (S), Endurance (E), Combined Strength and Endurance (S&E), and the Control (C) Groups' Respiratory Exchange Ratio at the Second Ventilatory Threshold

Group	n	Pre-test	Mid-test	Post-test
S	10	1.02 ± 0.06	1.02 ± 0.06	1.03 ± 0.07
E	7	1.01 ± 0.03	1.01 ± 0.04	1.02 ± 0.08
S&E [a]	8	0.94 ± 0.09	0.95 ± 0.06	0.99 ± 0.08
C	6	0.97 ± 0.02	n/a	0.98 ± 0.04
All U/E	12	1.01 ± 0.06	1.01 ± 0.07	1.01 ± 0.07
All L/E	19	0.97 ±0.07	0.98 ± 0.05	1.01 ± 0.08

Note. The values represent the group mean ± standard deviation. [a] Denotes the overall significantly lower RER of the S&E group across the three testing sessions as compared to the other two training groups.

Muscle Cross Sectional Area

Biceps Brachii

The groups' mean and standard error of the mean for biceps brachii muscle cross sectional area, as determined by the sonographic method, are presented in Table 4-15. The three-way (Training Group x Mode of Mobility x Test Session) ANOVA with repeated measures on the last factor did not reveal any significant interactions or main effects (Tables A5-13).

Table 4-15

Training Group by Test Session Means for the Strength (S), Endurance (E), Combined Strength and Endurance (S&E), and the Control (C) Groups' Biceps Brachii Muscle Cross Sectional Area (cm^2)

Group	n	Pre-test	Mid-test	Post-test
S	9	13.8 ± 1.7	14.2 ± 1.8	13.7 ± 1.5
E	9	13.0 ± 2.0	12.7 ± 2.1	12.4 ± 2.1
S&E	8	13.3 ± 1.4	13.1 ± 1.7	12.6 ± 1.2
C	8	10.1 ± 0.7	n/a	9.9 ± 0.7

Note. The values represent the group mean ± standard error of the mean.

Rectus Femoris

Of the 37 participants enrolled in this study only 20 could adequately perform the knee extensor strength testing procedures. Of these participants 19 were able to attend all three sonographic assessments. Due to the small sample size, and resulting empty cells, the originally planned three-way ANOVAs with repeated measures on the Test Session factor were not performed on the rectus femoris muscle cross sectional data. Therefore, a two-way (Training Group x Test Session) ANOVA with repeated measures on the Test Session factor was performed (Table A5-14). This analysis, which examined all four training groups (S, E, S&E, and C) and the pre to post-test data, resulted in a significant Test Session main effect (F (1, 16) = 9.73, p = .007). The Test Session main effect demonstrates that there was a significant increase in the cross sectional area of the rectus femoris muscle for the entire experimental sample over the course of this 12 week study. Because the Training Group x Test Session interaction was not significant it was not possible to determine whether the changes in any given study group were significant. The groups' mean and standard error of the mean for rectus femoris muscle cross sectional area are presented in Table 4-16.

Table 4-16

Training Group by Test Session Means for the Strength (S), Endurance (E), Combined Strength and Endurance (S&E), and the Control (C) Groups' Rectus Femoris Muscle Cross Sectional Area (cm^2)

Group	n	Pre-test	Mid-test	Post-test
S	4	3.8 ± 0.6	4.2 ± 0.5	4.8 ± 0.8
E	3	3.8 ± 0.2	3.4 ± 0.7	3.7 ± 0.3
S&E	6	3.9 ± 0.4	4.2 ± 0.3	4.6 ± 0.4
C	7	3.9 ± 0.7	n/a	4.5 ± 0.7

Note. The values represent the group mean ± standard error of the mean.

Creatine Kinase

The three-way (Training Group x Mode of Mobility x Test Session) ANOVA with repeated measures on the Test Session factor are presented in Table A5-15. None of these analyses demonstrated statistically significant interactions or main effects. Table 4-17 presents the groups' mean and standard error of the mean for creatine kinase concentration.

Table 4-17

Training Group by Test Session Means for the Strength (S), Endurance (E), Combined Strength and Endurance (S&E), and the Control (C) Groups' Concentration (U/L) of Creatine Kinase

Group	n	Pre-test	Mid-test	Post-test
S	9	50.1 ± 8.9	64.6 ± 7.6	60.3 ± 11.9
E	7	54.0 ± 10.5	52.3 ± 9.0	45.9 ± 7.9
S&E	6	40.7 ± 6.4	68.7 ± 10.5	46.6 ± 11.7
C	7	56.1 ± 16.0	n/a	54.4 ± 13.3

Note. The values represent the group mean ± standard error of the mean.

Endocrine

Table 4-18 presents the groups' mean and standard error of the mean concentrations of the two serum derived hormones evaluated in this study.

Table 4-18

Training Group by Test Session Means for the Strength (S), Endurance (E), Combined Strength and Endurance (S&E), and the Control (C) Groups' Concentrations of Sex Hormone Binding Globulin and Serum Total Testosterone

	Group			
Test Session	S	E	S&E	C
Sex hormone binding globulin (nmol/L)				
Pre-test	57.69 ± 9.58	43.94 ± 6.27	53.61 ± 9.51	82.40 ± 19.50
Mid-test	59.33 ± 9.44	41.72 ± 8.12	49.94 ± 5.32	n/a
Post-test	59.03 ± 8.71	41.48 ± 4.85	61.73 ± 10.45	84.39 ± 13.91
n	10	9	8	7
Serum Total Testosterone (nmol/L)				
Pre-test	2.61 ± 0.73	3.08 ± 0.67	3.06 ± 0.71	2.73 ± 0.71
Mid-test	2.93 ± 0.78	3.46 ± 0.77	3.18 ± 0.69	n/a
Post-test	3.28 ± 0.79	2.68 ± 0.79	3.06 ± 0.74	3.22 ± 0.63
n	10	9	7	7

Note. The values represent the group mean ± standard error of the mean.

Sex Hormone Binding Globulin

The three-way (Training Group x Mode of Mobility x Test Session) ANOVA with repeated measures on the Test Session factor is presented in Table A5-16. There were no significant interactions or main effects found with this analysis.

Serum Total Testosterone

The three-way (Training Group x Mode of Mobility x Test Session) ANOVA with repeated measures on the Test Session factor is presented in Table A5-17. This analysis did not demonstrate any statistically significant interactions or main effects.

Urinary Free Cortisol

The groups' mean and standard error of the mean concentrations of urinary cortisol are presented in Table 4-19. The three-way (Training Group x Mode of Mobility x Test Session) ANOVA with repeated measures on the Test session factor revealed a significant (F (1, 25) = 5.24, p = .031) Mode of Mobility x Test Session interaction (Table A5-18). This ANOVA procedure used the pre to post-test measurement data from the S, E, S&E, and C study groups. The Newman-Keuls multiple comparison post hoc analysis of the significant Mode of Mobility x Test Session interaction found no significant difference in the pre-test urinary cortisol concentrations between the wheelchair users and those who ambulated (p = .45). As a cohort, the ambulatory participants demonstrated a significant decrease in urinary cortisol concentration by the end of the 12 week study (p = .022). The ambulatory participants also completed the study with concentrations of urinary cortisol that were significantly lower than the wheelchair users (p = .0007). The Training Group x Test Session interaction was

Table 4-19

Training Group by Test Session Means for the Strength (S), Endurance (E), Combined Strength and Endurance (S&E), and the Control (C) Groups' Concentration (nmol/24 h) of Urinary Free Cortisol

Group	n	Pre-test	Mid-test	Post-test
S	10	37.7 ± 9.0	37.9 ± 8.8	38.6 ± 10.5
E	8	30.0 ± 4.8	21.4 ± 2.9	44.4 ± 10.2
S&E	7	41.4 ± 9.2	31.4 ± 6.8	67.2 ± 24.5
C	9	33.9 ± 7.7	n/a	22.6 ± 6.7

Note. The values represent the group mean ± standard error of the mean.

not significant, therefore it was not possible to learn whether any changes in urinary cortisol were training mode specific.

CHAPTER V
DISCUSSION

Person by Treatment Interaction

It appears that PTI played a minimal role in this study, suggesting that participants within each group responded to their training programs in a similar manner. Given the general absence of PTI in this study, the results of this study are more appropriately generalizable to a larger population, than if the existence of PTI had not been assessed (Bouffard, 1993). Zar (1984), suggests that comparisons of two correlation coefficients "works best if the two sample sizes are equal, or nearly so, or if neither is small" (p. 314). Zar does not specify a lower limit, but it is probable that the group sample sizes of this study would be considered small. Therefore, due to the small sample sizes in this study there is a risk that Zar's methodology was not sufficiently sensitive and that other cases of PTI may have been missed.

Body Composition

Although the skinfold measurements were carried out by the same certified tester for both testing sessions, the variability of the measurements for each participant during each session was high. This can be partly explained by the trend towards obesity for many of the participants (Roche, 1996), and also by the inability of some of the participants to relax their muscles as a result of increased muscular tone. This increased tone is a side effect of an upper neuron lesion, which is common in conditions such as: spinal cord lesions (above the cauda equina), cerebral palsy, traumatic brain injury, and multiple sclerosis.

No published training studies were found with which to compare the body composition results. However, the trend of this population to be sedentary and have a high Body Mass Index has been well documented (Roche, 1996). The intent of this study was to provide an individualized, moderately intense exercise program regardless of training group assignment. It seemed reasonable to have expected a significant change in body composition after the 12 week exercise program was completed. Total body mass may not have changed as a result of an increase in muscle mass off-setting any potential total body mass decrease. The absence of a change in the sum of three skinfold thickness measurement is more difficult to explain. A possible cause was an increase in caloric intake. Dietary records, however, were not kept by the participants in this study.

Strength Training

Elbow Flexors

The bilateral elbow flexion strength data provided no evidence of a diminished response of elbow flexor strength in the S&E group as compared to the S group as a result of a combined muscular strength and aerobic endurance training program.

Hickson (1980) stated that for interference to occur, the given muscle group must be exposed to both modes of exercise. Thus the mode of mobility was examined as a factor in the statistical analyses. Wheelchair users require the use of their UE to propel their wheelchairs and conduct the majority of their other everyday activities. The participants in the S&E group trained their UE for both strength and endurance as well as conducted their ADL. Those in the S group only added the strength training program to their weekly routine. Many of the wheelchair users daily activities would be considered as low intensity in nature and only stress the aerobic system. Therefore the S&E wheelchair users in this study had both low intensity and high intensity aerobic demands as well as the strength training stimulus placed on their UE. However, the UE of the ambulatory participants in both the S&E and S groups only experienced the muscular strength training component. Given the potential for interference, no attenuation of strength gains was documented in the wheelchair users in either the S or S&E groups. Nor was there a differential response found between the UE adaptations of the wheelchair users and the ambulatory participants. This study supports the other studies that have not detected interference effects in able-bodied participants (Kraemer et al., 1995; Nelson et al., 1990; Sale, MacDougall, et al., 1990).

Kraemer et al. (1995) also used a hybrid S&E training group that exclusively trained the UE for strength and the LE for endurance adaptations.

The authors found that, although not significant, there was a slightly enhanced strength training response in this hybrid S&E group versus the traditional S&E group that trained the LE for both strength and endurance and the UE for strength only. In the current study a trend was noted for the wheelchair users who trained their UE for both strength and endurance as compared to the S&E and S groups' ambulatory participants who only strength trained their UE. This trend for enhanced strength development was most pronounced during the first six weeks of the study and plateaued during the second half of the study. This finding, if demonstrated to be statistically significantly, would have suggested an attenuation of strength training gains. Had an interference effect been present, what was the mechanism? Was it the actual endurance training or the fact that these individuals continued to use their UE throughout the study for ADL that may have been responsible for the attenuation of strength adaptations? The results of this study suggest that a potential cause of the interference could have been the endurance training, rather than the daily activity. The wheelchair users in the S group were exposed to similar levels of daily activity as those in the S&E group. Daily activity could have been factor had there also been a lessened strength increase for the wheelchair users in the S group as compared to the ambulatory participants elbow flexor strength gains. These are speculations, however, and provide an interesting direction for further research.

These trends supported earlier findings that a differential response to the strength training stimulus may be a result of neurological status (Groeneveld, 1986; Horvat, 1987; Nilsson, et al., 1975; Tripp & Harris, 1991). Above the level of lesion, the myotome distribution tends to be normally innervated in participants with SCL (Somers, 1992). For participants with an upper motor neuron lesion, like CP/HI, even when there is no observable athetosis or spasticity at rest, with increasing work rates and/or fatigue, most of these individuals will demonstrate some abnormality in motor control (Ferrara & Laskin, 1997). For this reason, the type of disability may influence the rate and the magnitude of strength adaptations.

Knee Extensors

Although there were significant knee extensor strength gains observed for both the S and S&E groups, there was no evidence of an attenuation of the strength gains for the S&E group. Therefore, the LE 1RM determinations of this study do not support the existence of an interference effect. If an attenuation of knee extensor strength had been documented, the literature has demonstrated that there should have been a similar response between the two strength training groups until some critical point, six to eight weeks, when a differential response would have been observed in the S&E group (e.g. Hickson, 1980). In the current study, the response of the S&E group was a consistent improvement of LE strength throughout the course of the experiment, although of lesser magnitude than the S group. Post hoc analysis demonstrated that for each of the three test sessions the strength values for the S&E group were significantly greater than the S group. Given that the S&E group was significantly stronger than the S group at the onset of the study it was possible that the lessened response was an effect of the S&E group experiencing a physiological "law of diminishing returns". In other words, the strength training stimulus, which was applied equitably across participants, resulted in the S group improving their knee extensor strength more quickly.

Précis

As mentioned in the previous discussion on the elbow flexor 1RM results, the disproportionate increase in strength during the first six weeks of the study could be explained, in whole or in part, by the normal interplay between motor learning and physiological adaptations to strength training. It is common to observe a rapid increase in strength during the neurogenic or motor learning phase of strength training adaptations in the first four to eight weeks of a strength training program (Sale, 1988). This initial rapid increase in strength was assumed to be in part, a result of a more efficient and effective motor unit recruitment within the exercising muscles. Improved recruitment is a result of the combined adaptations of increasing synchronization of motor unit firing and an increased number of motor units firing at a given time. Motor skill development is the initial source of improved strength versus actual physiological changes to the muscle fiber morphology. Changes to muscle fiber morphology are first evident after six to eight weeks of a typical progressively overloaded strength training program (Sale, 1987). Given the lack of significant increases in skeletal muscle cross sectional area demonstrated in this study, the improvement in muscular strength must be associated primarily with the neurogenic adaptations.

Oxygen Consumption and Power Output

Peak Oxygen Consumption

Even though there was no significant increase in $\dot{V}O_{2\,peak}$ in either the E or the S&E groups, it should be noted that the participants' aerobic endurance performance test efforts were consistent. This observation is based on the peak HR and RER observed during each test session. There was no significant difference in the peak HR achieved between the testing sessions as determined by a two-way (Training Group x Test Session) ANOVA with repeated measures on the Test Session factor, (see Tables 4-10 & 4-12).

Although the participants' peak HR and RER were consistent among test sessions, what was the likelihood that the participants were working at a peak level? The three generally accepted $\dot{V}O_{2\,max}$ test criteria for the able-bodied population are a RER > 1.1, age predicted maximal HR plateau, and $\dot{V}O_2$ plateau (American College of Sports Medicine, 2000; MacDougall, Wenger, & Green, 1987). In practice a RER > 1.1 and a HR that approaches the individual's age predicted maximal HR would indicate that a peak performance was achieved. According to the data presented in Tables 4-10 and 4-12 the peak

HRs recorded were between 85% and 95% of the age predicted maximal HRs and the RERs were close to or exceeded the 1.1 threshold. Thus, one can conclude that the participants in this study were able to consistently provide a peak effort at each testing session.

Apparently the lack of a significant increase in $\dot{V}O_{2\,peak}$ was not due to the inability of the participants to perform the testing protocol. Therefore, the conclusion might be drawn that the stimulus for an aerobic endurance adaptation was not sufficient over the 12 week study for significant changes in $\dot{V}O_{2\,peak}$. During the author's pilot work significant improvements were observed in the $\dot{V}O_{2\,peak}$ achieved in a similarly prescribed aerobic endurance training program designed for both UE and LE ergometry. This 12 week pilot study investigated the differences between a continuous and interval training regimen. At the end of the 12 week training period there had been a significant increase in both the $\dot{V}O_{2\,peak}$ and the power output at $\dot{V}O_{2\,peak}$. However, there was no significant difference in the gains observed between the continuous and interval training groups. The participants in the pilot study were demographically similar to those in the current study except there were very few wheelchair users. The PTI analysis demonstrated that there was significant variability among the participants response to the endurance training program as measured by $\dot{V}O_{2\,peak}$.

Regardless of the degree of variability, when the training logs (HR) of the individual's in the E and S&E groups were examined it is clear that the participants did respond to the aerobic training program as was intended. The literature provides a number of examples of aerobic endurance training and people with physical disabilities. Unfortunately, the majority of this research has been performed on people with SCL. Despite a wide variety of training protocols and lesion levels the research has clearly demonstrated that participants with SCL are able to increase their $\dot{V}O_{2\,peak}$ with exercise intensities as low as 50% of their age predicted HR reserve (Connor, 1991; Hjeltnes, 1984; Millar & ward, 1983; Miles, et al., 1982; Pollock, et al., 1974; Sedlock, Fitzgerald, Knowlton, Schneider, 1983; Sedlock, Knowlton, & Fitzgerald, 1988; Wicks, Oldridge, Cameron, & Jones, 1983). A notable exception was Hooker and Wells (1989) study of 11 participants with SCL. This study demonstrated no change in $\dot{V}O_{2\,max}$ or maximal power output after an eight week training program at either 50-60% or 70-80% of maximal HR reserve. Wolman et al. (1994) demonstrated that their participants with brain injury showed significant increases in duration and workload after an 8 to 12 week endurance training program at 60 - 80% of the age predicted maximal HR. Given the available literature there is no reason to suspect that people with physical disabilities would not be able to increase their aerobic capacity as measured by $\dot{V}O_{2\,peak}$.

The current study incorporated a moderately high intensity interval training as part of the aerobic endurance training protocol. It is conceivable that the overall training stimulus was of a predominately anaerobic nature. Increased anaerobic power would help explain the marked increases in peak power output without a significant increase in $\dot{V}O_{2\,peak}$ over the course of the training program. Another contributing factor could be an increase in mode specific exercise efficiency over the course of the study. An improvement in mechanical efficiency would certainly result in a small increase in the ability to perform at any given $\dot{V}O_2$. However, an improvement in mechanical efficiency could not be the sole explanation for the significant increases in power output at $\dot{V}O_{2\,peak}$ and VT2 observed in this study.

Besides improvements in what is thought of as traditional skill related mechanical efficiency, the participants in the S and S&E groups also benefitted from significant increases in strength. These strength increases could have had an impact on the balance and stability of the participants which in turn would have allowed the participants to perform the activity with more effort going into the specific task. In addition the role of exercise and reduced spasticity is poorly understood. It is well documented that the individuals themselves often report a reduction in spasticity and in their medication requirements as a result of regular exercise (Ferrara & Laskin, 1998; Laskin & Anderson, In Press). This decrease in spasticity leads to a decrease in resistance to movement by the antagonist and would result in the participant being able to perform at greater work rates with a lessened $\dot{V}O_2$ requirement.

It appears likely that the adaptations to the endurance training program of this study reflect the principle of "specificity of exercise". The participants in the E and S&E groups adapted to the demands imposed on them by the endurance training program which was to stimulate an improvement in anaerobic power versus aerobic capacity.

Also of interest were the ranges of the $\dot{V}O_{2\,peak}$ observed; from 1.33 ± .24 L/min to 2.48 ± .16 L/min for the ambulatory participants and from 1.09 ± .25 L/min to 2.31 ± .07 L/min for wheelchair users. Even after 12 weeks of exercise training the participants in this study would be classified as sedentary to low active according to the able-bodied classification system developed by the American College of Sports Medicine (2000). These results support the growing body of evidence that people with physical disabilities, especially wheelchair users, have low aerobic fitness (Dearwater, LaPorte, Cauley, & Brenes, 1985; Department of Health and Human Services, 1991; Pitetti, 1993; Shephard, 1991).

Power Output at Peak Oxygen Consumption

The relative intensities and durations of the aerobic endurance exercise training was designed to be equivalent between those exercising on the arm and cycle ergometers. Because of the wheelchair users lesser muscle mass and lesser potential to recruit other accessory and stabilizing muscles, the absolute amount of effort may not have been equal. Perhaps, the wheelchair users in this study demonstrated a significant improvement in power output at $\dot{V}O_{2\,peak}$ because they received a slightly greater training stimulus than their ambulatory peers.

The data from the first half of the current study demonstrated that wheelchair users may have experienced an enhanced aerobic adaptation with combined muscular strength and aerobic endurance training as compared to training for aerobic endurance alone. It was found that the significant increase in power output at $\dot{V}O_{2\,peak}$ by S&Eu/e group was greater than the increase achieved by the Eu/e group. The data also documented a potential attenuation in the development of aerobic endurance during the second half of the experiment when training for both strength and endurance. The S&Eu/e demonstrated significant gains in power output at $\dot{V}O_{2\,peak}$ only during the first half of the 12 week study. An lessened response of aerobic endurance gains as a result of a combined strength and endurance exercise program has not been previously documented in the able-bodied literature. This potential adaptative response is representative of the need for further mode of mobility related research in people with physical disabilities.

Oxygen Consumption at the Second Ventilatory Threshold

The literature supports the belief that people with physical disabilities, like their able-bodied peers, will exhibit an increased ability to perform work for any given sub-maximal $\dot{V}O_2$ following a period of aerobic endurance training (Ferrara & Laskin, 1997; Figoni, 1997). The participants in both the E and S&E groups demonstrated no change in their $\dot{V}O_2$ at VT2, but did show a significant increase in power output by the end of 12 weeks of the endurance training program. The mean HR and RER at which VT2 occurred remained unchanged across the testing sessions for each of the four study groups. In addition, the percentage of the recorded peak HR at which VT occurred remained consistent across groups and pre to post-testing sessions at 74% to 81% of $\dot{V}O_{2\,peak}$. This study's findings are consistent with the literature with Bhambhani et al. (1995) reporting averaged values of 81% and 79.5% respectively for untrained and endurance trained individuals with quadriplegia. Lin et al. (1993) reported values of 73% to 77% in persons with paraplegia.

Power Output at the Second Ventilatory Threshold

The data from the current study showed that at the conclusion of 12 weeks of training there was no significant difference in power output at VT2 between the wheelchair using and ambulatory participants in the E and S&E groups. However, the S&E group as a whole concluded the study with a significantly greater increase in power output at VT2 then the E group. These findings suggests that there may have been an enhanced training effect in the S&E group. This enhanced effect was also noted for the wheelchair users in the combined training group for power output at $\dot{V}O_{2\,peak}$.

Précis

Hickson et al. (1988) suggested that adding a heavy resistance training component to an ongoing endurance training program would not have any negative effects on the expected endurance adaptations. The authors also speculated that high intensity aerobic endurance activities require the recruitment of Type II motor units. Therefore, Type II motor unit adaptation may benefit from a combined training program versus an endurance training program alone. The participants in the current study were not highly trained endurance athletes, In addition, the endurance training program did not require the participants to exercise for sustained periods of time above their VT2 (90 s work: rest ratio). The participants in the S&E group, because of their improved ability to recruit Type II motor units, may have been at an advantage during the aerobic endurance performance testing. In that case, the S&E group would be able to outperform the E group in both the power output at $\dot{V}O_{2\,peak}$ and the power output at VT2 measurements because of their concurrent adaptations to the muscular strength training program.

The literature supports the belief that people with physical disabilities can increase their $\dot{V}O_{2\,peak}$ following a period of aerobic endurance training (Ferrara & Laskin, 1997; Figoni, 1997). It has also been documented that central adaptations to an aerobic exercise program are limited for all wheelchair users regardless of their medical condition (Figoni, 1997; Shephard, 1991; Sorg, 1993). In the current study it was shown that the $\dot{V}O_2$ at peak exercise and VT2 did not change in either the E or S&E groups, whereas the power output significantly increased for the wheelchair users only at peak exercise and both UE and LE at VT2. As discussed earlier, the adaptations to the endurance training program appear to be a result of improved mechanical efficiency and anaerobic power. Given this scenario, the increase in power output at VT2 or $\dot{V}O_{2\,peak}$ may represent a peripheral adaptation to endurance training. This ability to adapt peripherally to endurance training is not dependent on the amount of working muscle mass as it would be for central adaptations. Therefore, when evaluating an aerobic endurance training program which includes wheelchair users it would be prudent to include power output measurements.

It was noteworthy that the current study did not demonstrate significant improvements in aerobic capacity using the indicators of $\dot{V}O_{2\,peak}$ and $\dot{V}O_2$ at VT2. This suggests that not only should $\dot{V}O_{2\,peak}$ and $\dot{V}O_2$ at VT2 be used to evaluate aerobic capacity, but that the power output (exercise resistance) at peak exercise and VT2 should also be considered as objective measures of aerobic capacity. Traditionally, the "gold standard" in exercise physiology literature has been $\dot{V}O_{2\,max}$ (American College of Sports Medicine, 2000). As with any standardization, this makes the comparison of multiple studies feasible. However, in the clinical environment, it is important to have a variety of measurement criteria available to document change. This choice allows for flexibility in test administration, and more important, it may allow for a more appropriate approach for documenting cardiorespiratory fitness in the wheelchair using population in research and in the clinic. A documented increase in the power output (W) performed at VT2 or $\dot{V}O_{2\,peak}$ is an image that may be more "user friendly" to the client than the traditionally reported $\dot{V}O_2$ values (L/min or ml/kg/min).

Muscle Cross Sectional Area

The findings presented in Appendix 2, show that the use of diagnostic ultrasound for muscle cross sectional area was reliable and valid. The lack of observed hypertrophic changes was probably not the result of faulty detection, but instead a result of a strength training program that may not have adequately promoted a hypertrophic response in either the biceps brachii or the rectus femoris muscles. However, the strength training for both that S and S&E groups was successful in stimulating neuromuscular adaptation, as indicated by the significant improvements in the 1RM determinations for both the elbow flexors and knee extensors. A number of studies have looked at strength training for people with physical disabilities (e.g. Groeneveld, 1986). They have all been successful in improving the participant's 1RM or 8RM strength. However, none of them have attempted to demonstrate skeletal hypertrophy using non-invasive means. Based on the available literature and pilot study experience we attempted to provide a progressive moderately intense training program (Ferrara & Laskin, 1997; Figoni, 1997; Green, 1996). The results of this study show the success of the strength training program was limited, due to the lack of skeletal muscle hypertrophy.

The lack of hypertrophy may well be related to the relatively novice status of the participants. As the 1RM testing procedure was a novel activity for the majority of the participants in this study, they may not have performed a true 1RM during the pre-test (Mayhew, Ball, & Bowen, 1992). The participants' performances during the pre-test may not have reflected an actual 1RM attempt, but rather a "best" effort given their experience (Ferrara & Laskin, 1997; Laskin & Anderson, In Press). Using this "best" effort to prescribe the strength training program, the intended initial average intensity of 70% may not have been achieved. For example, if the participant's pre-test (best effort) 1RM was 100 kg and their actual 1RM was 115 kg, then when the initial program was set up for 70 kg, they were not lifting 70%, but rather 60% of their true 1RM. The 1RM was not formally reevaluated until the mid-testing period. It would be expected that after six weeks of strength training and experience with the equipment that the recorded 1RMs would more accurately reflect the participants true ability. To determine if the participants' mid-test performance would more closely match their actual 1RM, the participants' 1RM performance was compared to the predicted 1RM. The predicted 1RM was based on their 8RM data (pre and mid-test) using the Strength Disk Program (Strength Disk, B. E. Software, Lincoln, NE). This comparison was performed on both the pre-test and mid-test data. The comparison demonstrated that the participants' actual pre-test 1RM ranged from 5% to 25% less than the predicted 1RM based. The mid-test comparison showed a range of ± 5% difference between the actual and the predicted 1RMs. These findings support the suggestion that the first six weeks of the strength training program may not have provided a sufficient strength training stimulus to induce hypertrophic changes.

There is no question that significant neuromuscular adaptations that occurred in both the S and S&E groups. However, the lack of documented hypertrophy does not preclude other peripheral adaptations taking place at the cellular level. Had muscle biopsies been performed in this study it is likely that increases in the contractile proteins would have been reported. These increases may have been observed as an increased of proteins in the actin and myosin filaments.

A criticism of the concurrent strength and endurance training literature is that the altered strength gains observed in the S&E group may be a result of over training. Though nonspecific, a indicator of muscle damage is an increase serum concentration of creatine kinase (Graves et al., 1987). If the strength gains are diminished in the S&E group as compared to the S group and the levels of creatine kinase remain within normal limits, then the evidence for chronic muscle damage would be minimized (Graves et al., 1987; Houmard et al., 1990). In the current study all group mean values for serum creatine kinase were considered clinically normal indicating that overtraining did not occur (McDonough, 1994).

Creatine Kinase

No studies were found that specifically used creatine kinase as a marker of potential skeletal muscle damage in people with physical disabilities. All group mean values were considered clinically normal (McDonough, 1994). The participants' self reports (no muscle soreness, no alterations in sleep or appetite, no decrease in resting HR) support the argument that overtraining would not have been responsible had any limitations in muscular strength gains been observed in the current study (Graves et al., 1987). The lack of any significant increase in creatine kinase concentration in the current study only supports the claim that muscle damage did not occur which does not preclude the possibility of overtraining.

Endocrine

Except for serum testosterone, which will be discussed later, the training groups' means as well as the individual hormone concentrations were within clinically accepted ranges (McDonough, 1994).

Presently the literature does not provide any examples of chronic hormonal adaptations to simultaneous training for muscular strength and aerobic endurance. Observing chronic changes in hormone concentrations such as sex hormone binding globulin, serum total testosterone, and urinary free cortisol may help to explain the mechanism of a lessened strength training response in a combined training program. Several recent studies in the able-bodied have addressed this concern (Bell, et al., 1997; Bell, Syrotiuk, Martin, Burnham, & Quinney, 2000; Kraemer et al., 1995).

Bell et al. (2000) reported that they found no significant changes in serum concentrations of sex hormone binding globulin in either the S or S&E groups. The current study revealed the same pattern. It appears that the strength training programs in all of these studies were not sufficient to stimulate an increase in this important testosterone binding agent. However, sex hormone binding globulin as well as testosterone tend to Had there been a significant change in sex hormone binding globulin this would have indicated a corresponding change in the absolute amount of bound serum testosterone. In either case it could indicate there was an increase in the free or unbound/bioactive form of testosterone depending on whether the serum total testosterone had increase or decreased. As long as the difference between the serum total testosterone and the sex hormone binding globulin increased then the suggestion is more of the unbound form of testosterone would be available to stimulate protein synthesis in the skeletal muscle (Adlercreutz et al., 1986; Häkkinen, 1989; Viru, 1992). However, as in the other three studies that examined hormone responses in combined muscular strength and aerobic endurance training (Bell et al., 1997; Bell et al., 2000; Kraemer et al., 1995), the current study also demonstrated no significant changes in serum total testosterone over the duration of the study.

Had the participants' gender been included in the analysis of serum total testosterone as an independent factor, a gender related interaction main effect would have been expected. The literature reviewed stated that able-bodied men normally have significantly higher serum level of total testosterone compared to able-bodied women, 2.7 - 10.7 nmol/mL for men and 0.69 - 2.6 nmol/L for women (Guyton & Hall, 1996; McDonough, 1994). This was not the case in the current study. Examination of the raw data revealed that the values for the men in this study were well within normal limits. However, for 8 of the 12 women in this study, the serum total testosterone values were more than double the upper limit of normal. Potential reasons for these results are either the serum total testosterone levels and their response to exercise in these physically disabled women varied dramatically from that found in the able-bodied population, or there was a systematic error introduced into the assay protocol. There was a lack of literature reporting serum total testosterone values for people with physical disabilities in general, and/or following an exercise program. There was also a lack of literature suggesting that people from the disability groups used in this study would have serum total testosterone concentrations different than the able-bodied population. Since the assays were all performed at the same time with no regard for training group, disability type, or gender, it is unlikely that a systematic error was introduced selectively into the women's samples. Had this study used participants from a specific disability group an argument could be made that the serum total testosterone levels found were as a result of a factor unique to that population.

One must also consider that just because a chronic change in the serum concentrations of sex hormone binding globulin and total testosterone were not observed in this study does not mean that there were no influence on these endocrine variables. Had we elected to evaluate the acute responses to these hormones we may have observed to adaptation of increased concentrations of hormone in the serum 45 to 60 minutes post exercise bout. The responsiveness of these hormones will increase as an adaptation to training. Therefore, since the methods of the current study were to draw blood between 4 and 6 PM with the participants refraining from formalized exercise for at least 48 hours any adaptations related to an acute bout of exercise were obscured.

A criticism of some concurrent strength and endurance training research has been that the lessened responses of strength gains in the combined training group may be a result of overtraining. Neary et al. (1994) presented evidence supporting the use of urinary free cortisol as an indicator of overtraining. Several concurrent muscular strength and aerobic endurance studies have recently been published addressing this concern. Bell et al. (1997) found a differential response of the S&E group in their urinary free cortisol concentrations over the course of a 16 week training study. However, the differences were not between training groups but, rather between genders within the S&E group. Bell et al. (2000) also reported a gender based differential response of urinary free cortisol concentrations to exercise training. In both of these studies there was a significant increase in urinary free cortisol for the women as compared to the men in the S&E group.

In the current study the ambulatory participants as a cohort completed the 12 week study with significantly decreased urinary free cortisol concentrations. The ambulatory cohort also finished the study with significantly lower urinary free cortisol concentrations than the wheelchair users. Unfortunately the Training Group x Test Session interaction was not significant. The results do suggest that there may be a mode of mobility differential response to urinary free cortisol concentrations. The data also demonstrated an apparently large increase in urinary free cortisol from the mid-test to the post-test session for the E and S&E groups. Had these same group demonstrated a similar trend in creatine kinase concentrations there would be some strong evidence to suggest that these groups may have been experiencing overtraining. However, this was not the case. These and other non-significant findings reinforce the need to continue this line of research. Continued study will help determine whether they were just spurious numbers or is there some form of adaptation occurring.

CHAPTER VI
SUMMARY

The purpose of this study was to examine whether or not an adaptational incompatibility would be observed in people with physical disabilities regardless of their mode of mobility when presented with a moderate, progressive, combined strength and endurance training exercise program. The expectation, from pilot work and the literature reviewed, was that either no antagonism would exist (e.g., Nelson et al., 1990; Sale, MacDougall, et al., 1990) or that adaptations to strength training would be impaired (e.g., Bell et al.,1991; Dudley & Djamil, 1985; 1991; Hickson, 1980; Sale et, Jacobs, al., 1990). If the adaptations to strength training were impaired, it would be observed as a lessened hypertrophic response and/or a diminished 1RM (e.g., Dudley & Djamil, 1985; Hickson, 1980). Embedded within the current experiments' research design was the possibility of observing disability specific and mode of mobility specific physiological adaptations to single mode and combined modes of exercise.

Following are the hypotheses that were explored in the current study, followed by a summary of the pertinent findings.

Primary Hypothesis

Concurrent muscular strength and aerobic endurance training has no adverse effect on strength training adaptations as compared to muscular strength training alone.

Both the S and S&E groups demonstrated significant gains in their elbow flexor and knee extensor strength over the course of the 12 week experiment. However, no significant differences in elbow flexor or knee extensor strength gains were demonstrated between the S and S&E groups as measured by the participants' 1RM. The diagnostic ultrasound procedures demonstrated that there were no significant changes in biceps brachii and rectus femoris cross sectional area for any of the experimental training groups. Therefore, since the gains in muscular strength of the S&E group were not attenuated by the concurrent aerobic endurance training program, the current study does not support the existence of an interference effect as described by Hickson (1980), thus supporting the findings of McCarthy et al. (1995) Nelson et al. (1990), and Sale et al. (1990). It appears however, that strength training facilitated the ability of the participants in the S&E group to work at significantly higher power outputs at VT2 and $\dot{V}O_{2\,peak}$ as compared to the E group.

Secondary Hypotheses

1) The mode of mobility has no effect on the rate or magnitude of the adaptations to:

   a) muscular strength training

The study demonstrated that the initial UE strength of the wheelchair users in this study was significantly greater than in the participants who ambulate. The significantly greater increase in the wheelchair users' elbow flexor strength compared to the ambulatory between each of the three testing sessions suggested that there may be an enhanced strength training adaptation from daily wheelchair use. This enhanced effect was observed for the wheelchair users in all four study groups. The issue of the effect of daily wheelchair use on the adaptation to muscular strength training warrants further study especially in the wheelchair athlete population.

b) <u>aerobic endurance training</u>

The ambulatory participants in this study demonstrated significantly higher values for $\dot{V}O_{2\,peak}$, $\dot{V}O_2$ at VT2, PO at $\dot{V}O_{2\,peak}$ and PO at VT2 compared to the wheelchair users. This experiment did not find any evidence to suggest that mode of mobility group influenced the adaptations to the aerobic endurance training program.

c) <u>concurrent muscular strength and endurance training</u>

The analyses of the SE group data demonstrated a potential enhanced adaptation to the power output at $\dot{V}O_{2\,peak}$ for the wheelchair users as compared to the ambulatory participants. As an independent variable it appears that mode of mobility is potentially sensitive to the variations in physiological performance and adaptation to endurance exercise.

2) The type of physical disability has no effect on the rate or magnitude of the adaptations to:

a) muscular training

b) aerobic endurance training

c) concurrent muscular strength and aerobic endurance training

Unfortunately the small sample size and the number of types of physical disabilities represented in this study resulted in several cells where $\underline{n} \leq 2$. Therefore, the author was unable to pursue any statistical procedures based on type of disability.

Even though this study did not document an attenuation of the strength gains in the S&E group, it has added to the scope of clinically useful, if tentative, knowledge in terms of mode specific physiological adaptations. Due to the small sample size and resulting relatively large variances of many of the dependent variables, the current study is limited in its generalizability. In addition to the potential lack of generalizability, the inherent risk of Type II error means that there may have been significant effects that were missed (Cohen, 1988). However, his study showed that a group of low to moderately active people with a variety of physical disabilities can successfully complete a moderately rigorous 12 week training program and the associated testing procedures. It also showed that performance testing of both muscular strength and aerobic endurance is reliable when administered to a group of people of mixed physical disabilities. Diagnostic ultrasound was introduced as a useful method of evaluating skeletal muscle cross sectional area. The practical application of a better understood exercise response in this population (i.e., utilizing a combined strength and aerobic endurance exercise program) is critical to the advancement of current fitness and rehabilitation programs. This study has clearly indicated the need for a more comprehensive understanding of the physiological adaptations of people with physical disabilities to muscular strength and aerobic endurance training.

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APPENDIX 1

PILOT STUDY: RELIABILITY OF PEAK OXYGEN CONSUMPTION AND VENTILATORY THRESHOLD MEASUREMENTS

Purpose

The purpose of this pilot study was to determine the reliability of peak oxygen consumption ($\dot{V}O_{2\,peak}$) and second ventilatory threshold (VT2) measurements for a typical recreational group of people with physical disabilities.

Participants

Forty-two individuals with physical disabilities who were already participating in a aerobic endurance training study at the Rick Hansen Center, University of Alberta volunteered to participate in this study. To volunteer for the study each participant was required to sign the informed consent as approved by the Faculty of Physical Education and Recreation Human Ethics Committee. All potential participants were screened for current musculoskeletal problems that would predispose them to exercise related injuries. All of the participants had some experience in an organized exercise program, although none had participated in extensive physiological testing prior to the onset of this study. This study did not require that participants undergo any testing that deviated from the study in which they were currently involved. The participants were required to participate in three pre-study and two post-study aerobic endurance tests. Table A1-1 presents the basic demographic data of these participants. The participants ranged from 21 to 58 years old.

Table A1-1

Participant Demographics

Number	Gender	Mode of Mobility	Medical Diagnosis
6	women	ambulatory	5 - CPHI[*] 1 - MS[†]
19	men	ambulatory	1 - AMP[‡] 9 - CPHI 3 - MS 2 - SCL[**] 4 - Other [††]
6	women	wheelchair user	4 - CPHI 1 - Polio[‡‡] 1 - SCL (q)[***]
11	men	wheelchair user	6 - CPHI 3 - SCL (p)[†††] 2 - SCL (q)

Note. [*] Cerebral palsy and head injured. [†] Multiple sclerosis. [‡] Amputee (upper extremity). [**] Spinal cord lesion (central cord syndrome). [††] Blind.[‡‡] Polio myelitis. [***] Spinal cord lesion (quadriplegia). [†††] Spinal cord lesion (paraplegia).

Methods

Arm crank Ergometer Procedure

Peak oxygen consumption and VT2 were assessed using a continuous protocol of progressive resistance. The arm cranking was performed on a

Monark Arm Crank Ergometer using a Beckman Horizon Metabolic Cart and open circuit spirometry to determine both $\dot{V}O_{2\,peak}$ and VT2 in a combined test protocol. The initial load was set at a warm up minimal load of 25 Watts (W) and increased every 2 minutes until volitional fatigue was reached. For the individual's with quadriplegia 5 to 10 W increases for an 8 to 14 minute testing period was used. The second ventilatory threshold was determined by the ventilatory equivalent of carbon dioxide ($\dot{V}_E/\dot{V}_{co2}$) versus power output relationship (Bhambhani & Singh, 1988) and was assessed by locating the minimum point on the $\dot{V}_E/\dot{V}_{co2}$ versus power output curve (Bhambhani & Singh, 1985). Once VT2 had been achieved, and confirmed by the metabolic parameters, the final workload stages were decreased to one minute to determine peak. Heart rates were monitored via telemetry (Polar Favor).

Cycle Ergometer Procedure

Peak oxygen consumption and VT2 were assessed using a continuous protocol of progressive resistance. The leg cycling was performed on a Monark Cycle Ergometer with open circuit spirometry to determine both $\dot{V}O_{2\,peak}$ and VT2 in a combined test protocol. The initial load was set at 25 W and increased by either 12.5 W or 25 W every 2 minutes until volitional fatigue was reached. The choice of load increase was determined by the principal investigator based on reported fitness level and the initial heart rate response during the first two exercise loads. The goal was to have the participant reach volitional fatigue in 8 to 14 minutes.The second ventilatory threshold was determined by the $\dot{V}_E/\dot{V}_{co2}$ versus power output relationship (Bhambhani & Singh, 1988) and was assessed by locating the lowest point on the $\dot{V}_E/\dot{V}_{co2}$ versus power output curve (Bhambhani & Singh, 1985). Once VT2 had been achieved, and confirmed by the metabolic parameters, the final workload stages were decreased to one minute to determine $\dot{V}O_{2\,peak}$. Heart rates were monitored via telemetry (Polar Favor).

Inter-trial reliability was evaluated using the ICC procedure as described in Portney and Watkins (1993, chap. 26). Pre-test intra-test reliability was determined using all three pre-test measurements and post-test intra-test reliability was determined using both post test measurements. Statistical significance of inter-trial scores were determined by ANOVA with repeated measures on the Test Trial factor and independent t tests, respectively. STATISTICA™ for Windows (StatSoft, Tulsa, OK) was used for all statistical operations. The risk for type I error was set at $p \leq .05$ for all statistical tests. The range of ICC values for good reliability was set at > .75. Portney and Watkins suggest ICC values of > .90 are required to ensure validity as well.

Results and Discussion

Table A1-2 presents a summary of the pre and post-test performance data. For each of the four performance variables a series of two-way (Mode of Mobility x Test Trial) ANOVA with repeated measures on the Test Trial factor were performed on the pre-test trials and post-test trials separately. No significant differences were found. The pre-test and post-test trials best efforts

Table A1-2

Summary of Pre and Post-Test Performances

Performance Variable	Pre-test (3 trials)	Post-test (2 trials)
	M ± SEM	M ± SEM
$\dot{V}O_2$ (L/min) at VT2	1.23 ± 0.09 1.20 ± 0.10 1.24 ± 0.10	1.40 ± 0.11 1.39 ± 0.19
PO (W) at VT2	65.55 ± 8.82 70.95 ± 9.38 72.00 ± 9.82	81.69 ± 12.68 80.67 ± 11.58
$\dot{V}O_{2\,peak}$ (L/min)	1.86 ± 0.13 1.80 ± 0.13 1.93 ± 0.15	2.04 ± 0.18 2.05 ± 0.18
PO (W) at $\dot{V}O_{2\,peak}$	100.87 ± 13.05 114.18 ± 15.45 114.09 ± 17.12	123.14 ± 20.10 121.23 ± 18.22

were selected and then analyzed as a simple pre-post test repeated measures design. This analysis revealed significant differences ($p < .05$) between the pre-test and the post-test for all of the performance variables evaluated.

Table A1-3 presents the inter-trial reliability of the four measured performance variables for both the pre-test and post-test sessions. The ICC determinations show that in every case the reliability of the trials within a given test period would be classified as "good" as well as valid by Portney and

Table A1-3

Pre and Post-Test Inter-Trial Reliability

Performance Variable	Reliability	
	Pre-test (3 trials)	Post-test (2 trials)
$\dot{V}O_2$ (L/min) at VT2	ICC (2, 1) = 0.94	ICC (2, 1) = 0.98
	F (2, 66) = 0.04, p = .96	t (46) = 0.06, p = .95
PO (W) at VT2	ICC (2, 1) = 0.95	ICC (2, 1) = 0.98
	F (2, 66) = 0.14, p = .87	t (44) = 0.054, p = .96
$\dot{V}O_{2\,peak}$ (L/min)	ICC (2, 1) = 0.95	ICC (2, 1) = 0.97
	F (2, 66) = 0.23, p = .79	t (44) = -0.04, p = .97
PO (W) at $\dot{V}O_{2\,peak}$	ICC (2, 1) = 0.92	ICC (2, 1) = 0.98
	F (2, 63) = 0.23, p = .80	t (44) = 0.05, p = .96

Watkins, (1993). The F and t-tests reveal that there was also no significant differences between the trials for any given testing period. This pilot study concluded that measurements of $\dot{V}O_{2\,peak}$ and VT2 were reliable in a mixed sample of people with physical disabilities regardless of their mode of mobility. It is interesting to note that for each of the four performance variables the ICC determination is greater for the post-test period versus the pre-test period. The logical explanation for this phenomenon would be that the participants became more familiar with the apparatus and the procedures.

APPENDIX 2

PILOT STUDY: RELIABILITY AND VALIDITY OF DIAGNOSTIC ULTRASOUND FOR MEASURING SKELETAL MUSCLE CROSS SECTIONAL AREA

Purpose

The purpose of this pilot study was to determine the reliability and validity of using diagnostic ultrasound (DUS) as a means to assess skeletal muscle hypertrophy. The DUS procedure was expected to be demonstrated as both: 1) a reliable method of determining skeletal muscle cross sectional area, and 2) demonstrate concurrent validity as compared to magnetic resonance imaging (MRI)

Participants

Twenty healthy, volunteer participants (11 women and 9 men) were recruited from the Faculty of Physical Education and Recreation at the University of Alberta and the Millcreek Runners Running Club, Edmonton, Alberta. All had the study verbally explained to them. To volunteer for the study each participant was required to sign the informed consent form as approved by the Faculty of Physical Education and Recreation Human Ethics Committee.

Methods

All four extremities were utilized during this study. Each side was considered independent, therefore the sample size for both the upper extremity (UE) and lower extremity (LE) measurements was 40. Participants were scheduled to have their biceps brachii and rectus femoris assessed for cross sectional area by both DUS and MRI. Cross sectional area was evaluated initially by DUS followed by the MRI procedure within 48 hours. Each site was measured three times by two different sonographers followed by a single MRI examination. The order of the site measured and sonographer was randomly determined for each of the 20 participants. Participants were instructed to not exercise for the 12 hours preceding either assessment technique. Prior to DUS, the measurement sites were marked in the following locations: 1) the upper arm was marked at the midway point between the acromion process and the olecranon, and 2) the thigh was marked at a point 10 cm proximal from the patella. Participants were requested to re-marked the sites as necessary.

The ATL ESP Ultrasound Mark 9 (Bothell, WA) with an ATL Curved Linear C7-4 Transducer (Bothell, WA) was used following the manufacturer's protocol for the evaluation of superficial soft tissue structures. The specific settings for resolution and clarity were determined for each participant by the given sonographer. The participants were placed in a supine position with their extremities positioned for comfort and relaxation. A towel roll supported the knees in a slightly flexed position, while the arms were supported with the shoulder in 80 deg of abduction and the elbow flexed. Two 5 cm strips of white athletic tape (echo reflective) were placed 1 cm on either side of the evaluation mark in a circumferential direction to help the sonographer in location of the test site. The sonographer also ensured that the transducer was placed perpendicular to the longitudinal axis of the extremity. Once an image was obtained, the sonographer froze the image on the screen and followed the cross sectional area calculation procedure using the track ball and the screen curser. The sonographer traced along the inner edge fibrous sheath and for the biceps brachii did not include the brachial neurovascular bundle in the measurement. Both real time video and film copies of the procedure were obtained. This procedure of transducer placement and cross sectional area determination was completed three times by each of the sonographers.

The Shimadzu SMT-100X MRI (Kyoto, Japan) was used following the manufacturer's protocol for the evaluation of superficial soft tissue structures. The specific settings for resolution and clarity were determined for each participant by the technician. The participants were placed in a supine position with their extremities positioned for comfort and relaxation. A towel roll supported the knees in a slightly flexed position, while the arms were positioned along side of the trunk, with the palms up. A small almond was taped into position over top the four previously marked sites. The almond was placed so that its long axis was parallel to the long axis of the humerus or femur. Each almond was centered so that its widest point overlay the evaluation site. Almonds are frequently used as surface landmarks due to their oil content which ensures that they readily appear in the MRI image. Once the MRI image was acquired the identical circling procedure was followed as was performed during DUS procedures.

Intra-rater and inter-rater reliability was evaluated using the ICC procedure as described in Portney and Watkins, (1993, chap. 26). Intra-rater reliability was determined using all three DUS measurements whereas the inter-rater reliability was assessed using the mean of each sonographers determinations. Statistical significance of intra-rater and inter-rater scores were determined by one-way ANOVAs with repeated measures on the Test Trial factor and independent t tests, respectively. STATISTICA™ for Windows (StatSoft, Tulsa, OK) was used for all statistical operations. The risk for type I error was set at $p \leq .05$ for all statistical tests. The range of ICC values for good reliability was set at > .75. Portney and Watkins suggest ICC values of > .90 are required to ensure validity as well.

Concurrent validity was evaluated by an independent t test comparing the mean of all six DUS measurements with the MRI determination. A finding of no significant difference would suggest that the DUS technique could be used as a substitute procedure for measuring skeletal muscle cross sectional area (Portney and Watkins, 1993, chap. 6).

Results and Discussion

Table A2-1 presents the intra-tester and inter-tester reliability. The intra-tester reliability determinations resulted in ICCs of > .98 which, by Portney and Watkins' (1993) definition, were both reliable and valid. In addition the one-way

Table A2-1

Intra-Rater and Inter-Rater Reliability of Diagnostic Ultrasound Measurements

Sonographer - Extremity	#†	M ± SEM (cm^2)	n	Reliability
1 - LE	12	2.72 ± 0.21	40	ICC (3, 1) = .98
	3	2.71 ± 0.21	40	F (2, 117) = 0.01, p = .99
		2.68 ± 0.20	40	
2 - LE	12	2.47 ± 0.19	40	ICC (3, 1) = .98
	3	2.55 ± 0.19	40	F (2, 117) = 0.06, p = .95
		2.56 ± 0.19	40	
1 - UE	12	10.64 ± 0.71	38	ICC (3, 1) = 1.0
	3	10.83 ± 0.73	38	F (2, 111) = 0.02, p = .98
		10.77 ± 0.73	38	
2 - UE	12	10.92 ± 0.74	38	ICC (3, 1) = .99
	3	10.80 ± 0.75	38	F (2, 111) = 0.01, p = .99
		10.89 ± 0.75	38	
1 - LE	M	2.70 ± 0.21	40	ICC (2, 2) = .98
2 - LE	M	2.53 ± 0.19	40	t (78) = 0.62, p = .54
1 - UE	M	10.75 ± 0.72	38	ICC (2, 2) = 1.0
2 - UE	M	10.87 ± 0.74	3	t (74) = -0.12, p = .90

Note. † denotes the measurement trial. M denotes the average value of the three trials for each sonographer.

ANOVA with repeated measures on the Test Trial factor found no significant difference between each testers three measurements. The inter-tester reliability was also found to be high and the t - test was found to be not significant. It was concluded that the DUS procedure is a reliable procedure in the determination of biceps brachii and rectus femoris cross sectional area. These results agree with the findings by previous researchers using able-bodied participants and a variety of other LE muscle groups. What was unique about this pilot study was that an UE muscle group was included in the procedure.

Table A2-2 shows the results of the criterion validity determinations. It was found that for the LE measurements the DUS procedure would provide an excellent alternative (ICC (2, 2) = .96, t (70) = -1.21, p = .23) to the MRI standard. A similar finding was reported for the UE measurements (ICC (2, 2) = .93, t (70) = 2.70, p = .01) except that the DUS consistently over estimated the cross sectional area of the biceps brachii muscle. One reason for this overestimation was the difficulty in excluding the entire neurovascular bundle in the cross sectional determination with DUS image. A solution would be to include the neurovascular bundle in future comparative studies of the biceps brachii muscle. If only the DUS procedure is being utilized, however either

Table A2-2

Concurrent Validity of Diagnostic Ultrasound as Compared to Magnetic Resonance Imaging

Mode - Extremity	M ± SEM (cm^2)	n	Concurrent Validity
DUS - LE	2.76 ± 0.21†	3636	ICC (2, 2) = .96
MRI - LE	3.11 ± 0.20‡		t (70) = -1.21, p = .23
DUS - UE	10.81 ± 0.73†	3836	ICC(2, 2) = .93
MRI - UE	8.25 ± 0.60‡		t (70) = 2.70, p = .01*

Note. † value represents the average of six separate measurements by two sonographers for each of the participants. ‡ value represents the average of three separate measurements by one technician. * $p < 0.05$

approach would result in highly reliable measurements, according to the findings of this study.

This was one of the first attempts to evaluate the criterion validity of DUS. Both an UE and LE muscle group were evaluated in an able-bodied sample of the population. Given the high reliability found with the DUS in the pilot study with people with physical disabilities it is assumed that the criterion validity found with the DUS procedure is applicable to this population as well. Future investigators, however must take note of the significant over estimation of the biceps brachii muscle cross sectional area with DUS.

APPENDIX 3

CLASSIFICATION SYSTEMS

Table A3-1

An Overview of the Cerebral Palsy - International Sport and Recreation Association's Function Profiles for Athletes with Non-progressive Brain Injuries

Class	Functional Profile
Class 1	Moderate to severe spasticity - severe involvement of all four limbs. Poor trunk control and functional strength in upper extremities (UE).
Class 2 (lower)	Moderate to severe spasticity - severe involvement of upper extremities and trunk. Poor functional strength and control of UE. Propels wheelchair with legs.
Class 2 (upper)	Moderate to severe spasticity - severe involvement of lower extremities and trunk. Poor functional strength and control of lower extremities. Propels wheelchair with arms poorly.
Class 3	Fair functional strength and moderate control in UE. Almost full functional strength in dominant UE. Propels wheelchair with one or both arms slowly.
Class 4	Moderate to severe involvement of lower limbs. Functional strength and minimal control problems in UE.
Class 5	Good functional strength; minimal control problems in UE. Usually ambulates with an assistive device.
Class 6	Moderate to minimal involvement of all four limbs and trunk (typically athetoid); competes without an assistive device.
Class 7	Moderate to minimal hemiplegia. Good functional ability on non-affected side. Ambulates well.
Class 8	Minimally affected or monoplegic. Good coordination and balance.

Note. Adapted from "Disability and Sport," by K. P. DePauw, and S. J. Gavron, 1995, Champaign, Il.: Human Kinetics, p. 122.

Table A3-2

An Overview of the International Sport Organization for the Disabled's Les Autres Classification System

Class	Functional Profile
L1	Uses a wheelchair. Reduced function of muscle strength and/or spasticity in dominant arm. Poor sitting balance.
L2	Uses a wheelchair. Either good function of the dominant arm and poor to moderate sitting balance or good sitting balance with reduced function of the dominant arm.
L3	Uses a wheelchair. Both good arm function and sitting balance.
L4	Ambulatory with or without assistive devices and braces or problems with standing balance together with reduced dominant arm function.
L5	Ambulatory with good arm function. Reduced function in the lower extremities or difficulty with standing balance.
L6	Minimal trunk or lower extremity impairment.

Note. Adapted from "Disability and Sport," by K. P. DePauw, and S. J. Gavron, 1995, Champaign, Il.: Human Kinetics, p. 124.

Table A3-3

An Overview of the International Stoke Mandeville Wheelchair Sports Federation's Functional Track Classification System

Class	Functional Profile
T1	Severe reduction of overall arm strength affecting hand grip and elbow extension; significant shoulder weakness and reduced triceps function.
T2	Limited if any function in one or both hands. Elbow extension (triceps) spared.
T3	Normal hand and arm function. Limitations in sitting balance, trunk rotation and unable to fixate the trunk.
T4	Normal upper body function. Good sitting balance and effective trunk rotation.

Note. Adapted from "Disability and Sport," by K. P. DePauw, and S. J. Gavron, 1995, Champaign, Il.: Human Kinetics, p. 125-127.

APPENDIX 4

INFORMED CONSENT

Physiological Adaptations to Concurrent Strength and Aerobic Endurance Training in an Active Adult Physically Disabled Population

James Laskin
Office Phone 492-3182 Home Phone 466-5918

Gordon Bell
Office Phone 492-2829 Home Phone 438-8816

CONSENT FORM

I understand that while involved in this study I will not participate in any other form of fitness training or activities without informing the Principle Investigators.

I have been informed of the low risk of potential injury in this study and I am aware that due to the requirement of maximal effort during the testing sessions I may experience short term muscle soreness and/or nausea. All contraindications of the procedure have been explained to me including the possibility of mild muscle soreness.

I understand that it is my choice to participate in this study. I also understand that I may withdraw from this investigation at any time should I so desire and that I may terminate a test or training session at any time. I understand that I may withdraw without prejudice to myself.

I understand that in order to collect the full one hundred dollar ($100.00) honorarium I must complete the full course of the study and attend the training sessions regularly.

I understand that all results and my name will be kept confidential by assigning a code to all the data, secured by the principle investigators. I also understand that all personal results and overall study conclusions will be made available to me upon the request. I also acknowledge that I have received a copy of the information sheet and of this informed consent.

I give my consult to be voluntarily involved in an investigation entitled

"Physiological Adaptations to Concurrent Strength and Aerobic Endurance Training in an Active Adult Physically Disabled Populations".

Subject Name

____

Address

____

Signed (subject)

____

Signed (witness)

____

Date ______________________________, 1993

APPENDIX 5

ANOVA TABLES

Table A5-1

Three-Way, Training Group x Mode of Mobility x Test Session, Analysis of Variance with Repeated Measures on the Test Session Factor for the Sum of Three Skinfolds Measurements (pre and post-test sessions only)

Source	df Effect	df Error	MS Error	F
Training Group (A)	3	25	1831.50	0.52
Mode of Mobility (B)	1	25	1831.50	0.29
Test Session (C)	1	25	52.69	2.43
A x B	3	25	1831.50	1.02
A x C	3	25	52.69	0.57
B x C	1	25	52.69	0.08
A x B x C	3	25	52.69	2.04

Note. $^{*}p < 0.05$, $^{**}p < 0.01$, and $^{***}p < 0.001$.

Table A5-2

Three-Way, Training Group x Mode of Mobility x Test Session, Analysis of Variance with Repeated Measures on the Test Session Factor for Body Mass Measurements (pre and post-test sessions only)

Source	df Effect	df Error	MS Error	F
Training Group (A)	3	29	753.97	0.12
Mode of Mobility (B)	1	29	753.97	1.66
Test Session (C)	1	29	1.61	0.21
A x B	3	29	753.97	0.32
A x C	3	29	1.61	1.28
B x C	1	29	1.61	0.69
A x B x C	3	29	1.61	0.09

Note. * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.

Table A5-3

Three-Way, Training Group x Mode of Mobility x Test Session, Analysis of Variance with Repeated Measures on the Test Session Factor for Elbow Flexor 1RM Strength Measurements (pre and post-test sessions only)

Source	df Effect	df Error	MS Error	F
Training Group (A)	3	29	1304.98	2.26
Mode of Mobility (B)	1	29	1304.98	1.16
Test Session (C)	1	29	51.92	36.56***
A x B	3	29	1304.98	3.14*
A x C	3	29	51.92	6.34**
B x C	1	29	51.92	10.10**
A x B x C	3	29	51.92	1.45

Note. * $p < .05$, ** $p < .01$, and *** $p < .001$.

Table A5-4

Three-Way, Training Group x Mode of Mobility x Test Session, Analysis of Variance with Repeated Measures on the Test Session Factor for Elbow Flexor 1RM Strength Measurements (pre, mid, and post-test)

Source	df Effect	df Error	MS Error	F
Training Group (A)	2	21	2118.61	0.59
Mode of Mobility (B)	1	21	2118.61	4.25
Test Session (C)	2	42	34.63	27.89^{***}
A x B	2	21	2118.61	2.05
A x C	4	42	34.63	6.05^{***}
B x C	2	42	34.63	10.19^{***}
A x B x C	4	42	34.63	0.90

Note. $^{*}p < .05$, $^{**}p < .01$, and $^{***}p < .001$.

Table A5-5

Two-Way, Training Group x Test Session, Analysis of Variance with Repeated Measures on the Test Session Factor for Knee Extensor 1RM Strength Measurements (pre and post-test only)

Source	df Effect	df Error	MS Error	F
Training Group (A)	3	16	25428.31	4.29*
Test Session (B)	1	16	844.14	33.76***
A x B	3	16	844.14	7.00**

Note. * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.

Table A5-6

Two-Way, Training Group x Test Session, Analysis of Variance with Repeated Measures on the Test Session Factor for Knee Extensor 1RM Strength Measurements (pre, mid, and post-test)

Source	df Effect	df Error	MS Error	F
Training Group (A)	2	10	30855.89	3.34
Test Session (B)	2	20	716.11	20.85***
A x B	4	20	716.11	2.91*

Note. * $p < .05$, ** $p < .01$, and *** $p < .001$.

Table A5-7

Three-Way, Training Group x Mode of Mobility x Test Session, Analysis of Variance with Repeated Measures on the Test Session Factor for Peak Oxygen Consumption (pre and post-test sessions only)

Source	df Effect	df Error	MS Error	F
Training Group (A)	3	26	0.63	2.30
Mode of Mobility (B)	1	26	0.63	1.98
Test Session (C)	1	26	0.03	5.68*
A x B	3	26	0.63	1.90
A x C	3	26	0.03	0.37
B x C	1	26	0.03	16.35***
A x B x C	3	26	0.03	1.57

Note. * $p < .05$, ** $p < .01$, and *** $p < .001$.

Table A5-8

Three-Way, Training Group x Mode of Mobility x Test Session, Analysis of Variance with Repeated Measures on the Test Session Factor for Oxygen Consumption at Ventilatory Threshold Two (pre and post-test sessions only)

Source	df Effect	df Error	MS Error	F
Training Group (A)	3	26	0.28	1.07
Mode of Mobility (B)	1	26	0.28	4.51*
Test Session (C)	1	26	0.02	0.96
A x B	3	26	0.28	1.32
A x C	3	26	0.02	1.39
B x C	1	26	0.02	0.00
A x B x C	3	26	0.02	1.14

Note. * $p < .05$, ** $p < .01$, and *** $p < .001$.

Table A5-9

Three-Way, Training Group x Mode of Mobility x Test Session, Analysis of Variance with Repeated Measures on the Test Session Factor for Power Output at Peak Oxygen Consumption (pre and post-test sessions only)

Source	df Effect	df Error	MS Error	F
Training Group (A)	3	24	4503.01	2.46
Mode of Mobility (B)	1	24	4503.01	0.79
Test Session (C)	1	24	116.93	34.96***
A x B	3	24	4503.01	0.96
A x C	3	24	116.93	4.73**
B x C	1	24	116.93	11.07**
A x B x C	3	24	116.93	3.85*

Note. * $p < .05$, ** $p < .01$, and *** $p < .001$.

Table A5-10

Three-Way, Training Group x Mode of Mobility x Test Session, Analysis of Variance with Repeated Measures on the Test Session Factor for Power Output at Peak Oxygen Consumption (pre, mid, and post-test)

Source	df Effect	df Error	MS Error	F
Training Group (A)	2	19	6498.76	3.18
Mode of Mobility (B)	1	19	6498.76	0.07
Test Session (C)	2	38	85.69	35.96***
A x B	2	19	6498.76	1.10
A x C	4	38	85.69	4.14**
B x C	2	38	85.69	12.24***
A x B x C	4	38	85.69	4.35**

Note. * p < .05, ** p < .01, and *** p < .001.

Table A5-11

Three-Way, Training Group x Mode of Mobility x Test Session, Analysis of Variance with Repeated Measures on the Test Session Factor for Power Output at Ventilatory Threshold Two (pre and post-test sessions only)

Source	df Effect	df Error	MS Error	F
Training Group (A)	3	24	1957.48	1.10
Mode of Mobility (B)	1	24	1957.48	4.11
Test Session (C)	1	24	48.62	56.42***
A x B	3	24	1957.48	0.58
A x C	3	24	48.62	11.04***
B x C	1	24	48.62	2.79
A x B x C	3	24	48.62	1.14

Note. * $p < .05$, ** $p < .01$, and *** $p < .001$.

Table A5-12

Three-Way, Training Group x Mode of Mobility x Test Session, Analysis of Variance with Repeated Measures on the Test Session Factor for Power Output at Ventilatory Threshold Two (pre, mid, and post-test)

Source	df Effect	df Error	MS Error	F
Training Group (A)	2	19	2586.41	0.76
Mode of Mobility (B)	1	19	2586.41	2.68
Test Session (C)	2	38	102.78	17.64***
A x B	2	19	2586.41	0.69
A x C	4	38	102.78	3.02*
B x C	2	38	102.78	0.96
A x B x C	4	38	102.78	0.79

Note. * $p < .05$, ** $p < .01$, and *** $p < .001$.

Table A5-13

<u>Three-Way, Training Group x Mode of Mobility x Test Session, Analysis of Variance with Repeated Measures on the Test Session Factor for Biceps Brachii Muscle Cross Sectional Area (pre and post-test sessions only)</u>

Source	df Effect	df Error	MS Error	F
Training Group (A)	3	26	35.46	1.23
Mode of Mobility (B)	1	26	35.46	0.58
Test Session (C)	1	26	1.75	0.97
A x B	3	26	35.46	2.66
A x C	3	26	1.75	0.15
B x C	1	26	1.75	0.02
A x B x C	3	26	1.75	0.51

<u>Note</u>. * <u>p</u> < .05, ** <u>p</u> < .01, and *** <u>p</u> < .001.

Table A5-14

Two-Way, Training Group x Test Session, Analysis of Variance with Repeated Measures on the Test Session Factor for Rectus Femoris Muscle Cross Sectional Area (pre and post-test only)

Source	df Effect	df Error	MS Error	F
Training Group (A)	3	16	2.96	0.19
Test Session (B)	1	16	0.25	9.73**
A x B	3	16	0.25	1.52

Note. * $p < .05$, ** $p < .01$, and *** $p < .001$.

Table A5-15

Three-Way, Training Group x Mode of Mobility x Test Session, Analysis of Variance with Repeated Measures on the Test Session Factor for Creatine Kinase (pre and post-test sessions only)

Source	df Effect	df Error	MS Error	F
Training Group (A)	2	16	697.22	1.27
Mode of Mobility (B)	1	16	697.22	1.00
Test Session (C)	1	16	923.75	0.13
A x B	2	16	697.22	0.22
A x C	2	16	923.75	0.07
B x C	1	16	923.75	1.63
A x B x C	2	16	923.75	0.62

Note. * $p < .05$, ** $p < .01$, and *** $p < .001$.

Table A5-16

Three-Way, Training Group x Mode of Mobility x Test Session, Analysis of Variance with Repeated Measures on the Test Session Factor for Sex Hormone Binding Globulin (pre and post-test sessions only)

Source	df Effect	df Error	MS Error	F
Training Group (A)	3	26	1665.54	2.04
Mode of Mobility (B)	1	26	1665.54	0.77
Test Session (C)	1	26	90.16	0.28
A x B	3	26	1665.54	1.34
A x C	3	26	90.16	0.71
B x C	1	26	90.16	0.85
A x B x C	3	26	90.16	0.31

Note. * $p < .05$, ** $p < .01$, and *** $p < .001$.

Table A5-17

Three-Way, Training Group x Mode of Mobility x Test Session, Analysis of Variance with Repeated Measures on the Test Session Factor for Serum Total Testosterone (pre and post-test sessions only)

Source	df Effect	df Error	MS Error	F
Training Group (A)	3	26	7.30	0.16
Mode of Mobility (B)	1	26	7.30	1.33
Test Session (C)	1	26	1.90	0.00
A x B	3	26	7.30	0.83
A x C	3	26	1.90	0.71
B x C	1	26	1.90	0.58
A x B x C	3	26	1.90	0.61

Note. * $p < .05$, ** $p < .01$, and *** $p < .001$.

Table A5-18

Three-Way, Training Group x Mode of Mobility x Test Session, Analysis of Variance with Repeated Measures on the Test Session Factor for Urinary Cortisol (pre and post-test sessions only)

Source	df Effect	df Error	MS Error	F
Training Group (A)	3	25	238.34	0.37
Mode of Mobility (B)	1	25	238.34	1.54
Test Session (C)	1	25	35.75	0.40
A x B	3	25	238.34	0.10
A x C	3	25	35.75	1.97
B x C	1	25	35.75	5.24*
A x B x C	3	25	35.75	0.85

Note. * $p < .05$, ** $p < .01$, and *** $p < .001$.