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UNIVERSITY OF ALBERTA

THE EFFECTS OF FAST VELOCITY CONTROLLED RESISTANCE TRAINING ON INDIVIDUALS WITH CEREBRAL PALSY

BY

©

KEITH BOYD HANSON

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

DEPARTMENT OF PHYSICAL EDUCATION AND SPORT STUDIES

Edmonton, Alberta

Spring, 1995

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The undersigned certify they have read, and recommended to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled The Effects of Fast Velocity Controlled Resistance Training on Individuals With Cerebral Palsy submitted by Keith Boyd Hanson in partial fulfillment of the requirements for the degree of Master of Science.

Dr. Robert Steadward

Dr. Gordon Bell

Dr. Marcel Bouffard

Dr. Yagesh Bhambhani

March 6, 1995

This manuscript is dedicated to Halldor and Norma, two athletes committed to their sport and the development of sports for individuals with cerebral palsy. Your excellence as athletes and people is unparalleled and it has been my great fortune to know both of you as a friend and as a coach.

Thank you.

Abstract

The following study examined the effects of fast velocity controlled resistance training of concentric knee flexion and extension on five individuals with cerebral palsy (CP). Using an ABA multiple baseline single subject design across subjects, subjects were randomly assigned to one of five baselines to undergo a fast ($4.19 \text{ rad}\cdot\text{sec}^{-1}$) velocity controlled resistance training program. Firstly, subjects were tested on a minimum of four baseline occasions. Secondly, subjects performed an eight-week fast velocity controlled training program performed three times per week. Finally, following the training program subjects underwent a 10 week detraining phase. Subjects were trained and tested every two weeks on the Cybex 340 Isokinetic Dynamometer to examine any changes in peak torque, average power, total work, and torque acceleration energy at six angular velocities and tested on muscular endurance. The results indicated no consistent effect across subjects in terms of the muscular performance at different angular velocities; between the dominant and non-dominant legs; or between flexion and extension. It was concluded therefore, a fast velocity controlled training program had a variable effect on torque, work, and power measures at various angular velocities of testing and a minimal effect on muscular endurance. The observed responses were highly individual and differential. Fast velocity controlled training may have had some positive effects for some individuals with CP on certain neuromuscular relationships which could be useful for enhancing sport and functional everyday tasks. However, the lack of change in some parameters after training suggests that the fast velocity controlled training may not be an effective

training regime for particular individuals with cerebral palsy.

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I owe a very special thank you to my family: my wife Kimberly Hanson and my children Andrea and Alyssa for their undying support throughout this Master's Degree. The thesis would not have been possible without the encouragement and unconditional love and friendship that Kimberly so generously provided. The time and effort she willingly sacrificed will never be forgotten. I wish to express my sincere appreciation to my mother and father in-law Margaret and James Taylor who not only cared for Andrea and Alyssa while I completed this project but provided support and care to Kimberly and me as well. I owe them all my profound thanks.

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CHAPTER I
INTRODUCTION

Overview of the Problem

Cerebral palsy (CP), has been defined as a non-progressive disorder of movement or posture that begins in childhood and is caused by a malfunctioning of, or damage to, the motor areas of the brain (Bleck, 1982). Milner-Brown and Penn (1979) have cited that the primary dysfunction for individuals with CP is the abnormal development of motor skills which resulted from damage to an developing or immature central nervous system. The severity of the dysfunction is related to the size and the location of the neurological lesion. Pape et al. (1990) stated that the most common form of CP is the spastic type which accounted for 50% to 75% of all cases and the athetoid type which accounted for approximately twenty five percent. Spasticity, the most frequently cited impediment to volitional movement for individuals with CP, is caused by damage to the motor cortex of the brain which passes signals related to voluntary movement via the pyramidal tract. The resultant spasticity is characterized by a hyperactive stretch reflex mechanism which causes the antagonist muscle to contract and limits the functional movement of the agonist muscle. This condition affects the ability of the individuals with CP to maintain normal muscle tone and control over the reciprocal contraction and relaxation of the opposing muscle groups (Holt, 1966). Volitional movement was also inhibited by limited and prolonged recruitment of the agonist muscle, causing inefficient muscular contractions (Sahrmann and Norton, 1977). The terms diplegia, quadriplegia, and hemiplegia describe the location of the spasticity (McCubbin, 1994).

Athetosis, characterized by slow, writhing and involuntary movements is the result of a defect in the inhibition of spinal and supraspinal reflexes. Consequently, while fine motor skills are handicapped, strength and walking ability are less affected (Shepard, 1990). Individuals with athetosis do not have as abnormally high muscle tone as spastic individuals, but, possess decrements in performance due to lack of coordination and mechanical efficiency as a result of impaired reciprocal inhibition and a usual lack of regular training and exercise. Authors such as Lundberg (1975; 1976; 1978) have asserted that individuals with CP lack normal mechanical efficiency. Deficits in mechanical efficiency are 12% and 16% for spastic and athetotic individuals, respectively, compared to 22% for non-disabled individuals. This low mechanical efficiency caused a high oxygen consumption to work performance ratio at submaximal and maximal exercise levels. The individual with CP displayed lower than average physical work capacity and aerobic power (approximately 10-30% below that of non-disabled controls), attributed to low mechanical efficiency, low levels of habitual exercise training and less muscle mass than non-disabled individuals (Shepard, 1990; Bar-Or et al. 1976; Lundberg, 1978).

Velocity controlled resistance training has been widely used by non-disabled individuals to improve muscular performance at a variety of training speeds. Physiological adaptations to velocity controlled resistance training were attained primarily as a result of neural and muscular adaptations. Recently, researchers have identified the need to study effects of velocity controlled resistance training in individuals with CP due to a number of key factors(McCubbin and Shasby, 1985: McCubbin, 1991). As outlined by Shepard (1990) the main physiological findings that limited an individual with CP was decreased muscle strength and endurance, and increased fatigue. Factors that contributed to these limitations may have included quantitative restriction in the form of less muscle mass compared to non-disabled individuals, and a change in the muscle fibre characteristics (Parker et al., 1992; Lundberg, 1978). Firstly, the amount of muscle mass was shown to be positively related to maximal force production of that particular muscle group and, as well, the amount of oxygen needed to supply that muscle for energy production. Parker et al. (1992) have maintained that stretch was an important stimulus for muscle growth. If stretch was applied to spastic muscle, it was vigorously opposed by the hypersensitive stretch reflex; therefore, the muscle was maintained in a shortened position, thus resulting diminished growth and less muscle mass due to the static and dynamic contractures within the muscle (Parker et al., 1992).

Secondly, strong tonic spasticity initially has been shown to recruit preferentially low-frequency, low-tension, slow motor units and selective disuse of fast motor units. Parker et al (1992) postulated that compared with the non-disabled, children with spastic CP lack suitable number of fast twitch fibres that are required to produce high intensity muscle power, compared to the non-disabled . Castle et al. (1979) found preferential atrophy of type II and more specifically type IIB muscle fibres in the lower extremities of individuals with CP.

The combination of specific muscle fibre atrophy, decreased muscle mass, decrements in reciprocal inhibition due to spasticity, and lack of general and specific training due to low activity levels seen in individuals with CP resulted in decreased muscular performance (Shepard, 1990). McCubbin and Shasby (1985) and McCubbin (1994) cited that improvement in motor performance in individuals with CP and non-disabled individuals could result from changes in physical and motor performance variables, particularly force development and speed of movement. Fast velocity controlled resistance training has been documented as an effective training stimulus for improving neuromuscular and muscular parameters (Bell & Wenger, 1992). Occurences of neuromuscular adaptations that could be important for the CP individual were increased motor unit excitability, decreases in twitch tension and contraction time and enhanced motor unit synchronization. As stated by Sale (1986, 1987) these neural changes accompanying strength improvement could result from increased activation of prime movers, greater involvement of synergist muscles and/or inhibition of antagonist muscle groups (Bell & Wenger, 1992). These enhancements to neuromuscular performance would certainly be postive adaptations for people with CP who lack certain neuromuscular relationships to elicit efficient muscular contractions and applications of force. Fast velocity controlled resistance training has also been shown to increase fast twitch muscle fiber area as a result of a greater recruitment of fast twitch motor units (Costill et al., 1979; Coyle , 1981; Sale, 1987). Since individuals with CP have been shown to have atrophy of fast twitch motor units and a decreased muscle mass, techniques such as fast velocity controlled resistance training may assist in promoting increased fast fiber area and increased muscle mass which in turn may improve muscular performance in sport situations. In addition, theories of resistance training maintain that for optimal improvement of athletic performance, training must simulate the sport movement as closely as possible in terms of anatomical movement pattern, contraction type and force, and velocity of the movement (Sale and MacDougall, 1981). Many athletes with CP are involved in sports that require high muscular force application at high velocities ie. running, swimming, cycling, and wheelchair track (in excess of 200 $deg \cdot sec^{-1}$); therefore, it would seem logical that these athletes should train at a high velocity specifically to improve their own performances.

Velocity controlled resistance training is of particular interest in the training of muscular performance and speed of movement of individuals with CP. The constant preset velocity allows for the training and improvement of muscular performance in dynamic conditions. McCubbin and Shasby (1985) and McCubbin (1994) have shown that it is possible to increase the speed of movement and torque development in individuals with CP with velocity controlled resistance training at a slow and intermediate velocity without any detrimental effects. Consequently, as supported by McCubbin and Shasby (1985), the investigation into the adaptation of individuals with CP to other velocities of isokinetic resistance training would be of value. As previously stated, athletes involved in sports that require fast velocity movements should be, in theory, trained at the velocity at which they perform in order to achieve optimal improvement.

Detraining has been described as a process whereby the muscular performance gained in the resistance training regime is typically lost at a similar or lower rate than the performance was gained following withdrawal of the training stimulus (Hakkinen, 1981, 1985; Staron et al., 1991; Narici et al., 1989). Detraining has been shown to result in loss of training adaptation deriding from decreased neural drive (Collinder & Tesch, 1992), decreased muscle fiber size (Hakkinen, 1981, 1985; Staron et al., 1991) or muscle cross sectional area (Narici et al., 1989) in relatively short periods of time (8-12 weeks) after the termination of a training program. Although there have been no investigations into the course of detraining following fast velocity controlled resistance training, it would be expected that the adaptations from such a training program would be lost with the cessation of training.

In studies where subjects have tended to be quite variable and individualistic in their presentation (such as in persons with CP), conventional research designs utilizing homogeneous groups were usually rejected. Therefore, in studying individuals with marked interindividual differences researchers have primarily used single subject designs where the subjects themselves serve as their own controls. In certain types of single subject designs a withdrawal of the treatment was used to demonstrate experimental control and permanence of the intervention if the performance does or does not revert back to baseline levels. In resistance training literature, detraining studies were generally used to study the reversability of a certain type of conditioning program. Most of the research in this area was conducted with non-disabled groups. To our knowledge there have been no studies on effects of detraining on disabled individuals. Therefore, the value of a detraining period could be useful from both a design standpoint and an informational viewpoint, in the study of velocity controlled resistance training in individuals with selected disabilities.

Researcher's Hypothesis

It was the hypothesis of the primary researcher that despite the acknowledged neurological and muscular deficits, individuals with CP would benefit from a fast velocity controlled training program and that improvements in muscular performance would be similar to those seen in the non-disabled population through the measurement of various physiological parameters. These parameters would then decrease backward to pretraining levels following a period of detraining.

Purpose

The purpose of this study was to answer the following questions:

1) How did individuals with CP respond to eight weeks of fast-velocity controlled resistance training program performed concentrically in both flexion and extension

and to 10 weeks of detraining following the fast velocity controlled resistance training program ?

2) Did they adapt to the velocity at which they were trained or to other velocities when tested over a range of angular velocities ?

3) Did any training effect gained decrease with 10 weeks of detraining ?

Delimitations

In order to investigate this question the scope of this study had to be restricted to the following:

1. Subjects had to have cerebral palsy and be able to ambulate with or without the use of assistive devises ie. cane;
2. Subjects had to be capable of completing the required speeds of testing with the lower extremity through knee extension and flexion;
3. Subjects had to be from the Edmonton area; and
4. Data collection was to have occurred between January, 1994 and August, 1994.

Limitations

Every attempt was made to control outside influences which may have affected the validity or reliability of the results. This study was conducted within the context of the following limitations:

1. Subjects who took part in this investigation did so on a voluntary basis, having completed all measurements as requested. It was assumed that all subjects would exert a maximal effort during all tests, adhere to their instructions regarding maintainence of current activity level outside the study and would adhere to their instructions regarding the rest required prior to laboratory measurements.
2. It was assumed that the test protocol and equipment were of sufficient specificity to answer the research question.

Definitions

Throughout the ensuing text the following terms were used as defined below:

Velocity controlled resistance training : Training using equipment that attempts to resist an application of a force while attempting to control velocity of movement throughout the range of motion (Bell and Wenger, 1992, p.235). This enabled the results of various training programs on traditional isokinetic devices (Cybex II) and other velocity controlled systems such as Hydra-fitness to be combined in order to study the various trends in this area of research (Bell and Wenger, 1992).

In the literature, angular velocities were grouped into three divisions, are as follows:

Slow angular velocities: Those velocities less than or equal to 1.75 rad·sec^{-1} (100 deg·sec^{-1}).

Intermediate angular velocities: Those velocities between 1.76 to 3.50 rad·sec^{-1} (101-200 deg·sec^{-1}).

Fast angular velocities: Those velocities between 3.51 and 5.24 rad·sec^{-1} (201-300 deg·sec^{-1}) (Bell and Wenger, 1992).

Peak Torque: The highest point achieved on the torque vs joint angle curve.

Average power: The total work by actual total contraction time.

Total work: The sum of the total area under the torque curves during the test repetitions.

Torque Acceleration Energy: The work performed in the first one eight second of torque production.

The following terms refer to the type of motor involvement characteristic in individuals with cerebral palsy.

Spasticity results from damage to the motor areas of the cerebrum causing a state of increased muscle tone. Spasticity is characterized by exaggerated stretch reflexes (the limb muscle is tight and contracts strongly with sudden attempted movements or stretching) and hypertonicity (increased muscular tone), causing a marked decrement in the ability to perform precise movements (Sherrill, 1986).

Athetosis results from damage to the basal ganglia (masses of grey matter located deep within the cerebral hemispheres of the brain) which causes an overflow of motor impulses to the muscles. Athetosis is characterized by slow, writhing movements that are uncoordinated and involuntary (Winnick, 1990).

Ataxia is a condition that results from damage to the cerebellum, which normally regulates balance and coordination. In ataxia, muscles are usually hypotonic and the person is extremely unsteady because of balance difficulties and lack of coordination (Winnick, 1990).

Throughout the manuscript certain abbreviations were used, the meanings of which are displayed in Table 1-1.

Table 1-1. Abbreviations used in the Manuscript

CP	- Cerebral palsy
CP-ISRA	- Cerebral Palsy International Sports and Recreation Association
SEM	- Standard error of measurement
ICC	- IntraClass Coefficient
EMG	- Electromyography
R-D	- Right Dominant
R-ND	- Right Non-Dominant
L-D	- Left Dominant
L-ND	- Left Non-Dominant
PT	- Peak Torque
AP	- Average Power
TW	- Total Work
TAE	- Torque Acceleration Energy
APE	- Average Power Endurance Test
TWE	- Total Work Endurance Test
PFE	- Percent Fatigue Endurance Test

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CHAPTER II
LITERATURE REVIEW

Introduction

Resistance training has been widely used to enhance athletic performance. The important goal of resistance training is to increase force generation capability of skeletal muscle. The ability to apply this increased force generation allows individuals to improve functional performances in sports by being able to run at a greater speed, cycle at a higher power output, increase speed of movement, increase short term and long term endurance and accelerate the body mass or external objects faster (Berger, 1982). Research has also demonstrated that resistance exercise improved neuromuscular function (Moritani and DeVries, 1979; Komi, 1979). Increased force generation and improved neuromuscular function were achieved through various types of resistance exercises designed to overload the muscle groups involved. This could be very important to individuals with cerebral palsy involved both in sport and activities of daily living.

This review of the literature has designated three sections related to this topic: 1) Physiological adaptations to velocity controlled resistance training; 2) Physiological adaptation to detraining; 3)Physiological adaptations of individuals with CP to resistance training and more specifically velocity controlled resistance training.

PHYSIOLOGICAL ADAPTATION TO VELOCITY CONTROLLED RESISTANCE TRAINING

In isokinetic muscle dynamometry, muscular contractions are dynamic and the velocity is controlled and maintained by an external mechanical device (Baltzopoulos and Brodie, 1989). Devices such as the Cybex II kept the limb motion at or near constant predetermined velocity. Resistance from an isokinetic device was developed in proportion to the force applied. Therefore, increased acceleration was met with increased resistance. A maximal volitional muscular contraction was met with maximum resistance throughout the entire range of motion (McCubbin and Shasby, 1985). Isokinetic dynamometry such as the Cybex II has been examined closely by a number of investigators to determine its reliability, validity, and the inherent problems associated with such a device (Bemben et al., 1988; Tredinick and Duncan, 1988; Baltzopoulus and Brodie, 1989).

Velocity controlled resistance training equipment as outlined by Bell and Wenger (1992) attempted to control the velocity of movement, simulated movement patterns found in many sports, and allowed maximal muscle contraction throughout the entire limb range of movement. As stated by Bell and Wenger (1992) a limitation to this equipment is the absence of the eccentric component of muscle contraction. Although Martindale and Roberts (1984) have suggested that eccentric muscular contraction in various sports is minimal (eg. rowing and cycling), it has been shown that concentric resistance training enhances eccentric strength (Peterson et al., 1989; Komi and Buskirk, 1986).

Velocity controlled resistance training has been considered a safe and effective means of increasing strength, and speed of movement in reciprocal movement patterns (Bell and Wenger, 1992; McCubbin and Shasby, 1985).

Perrine and Edgerton (1978) maintained that the force/velocity characteristics of skeletal muscle dictated that maximal tension was developed at slow velocities and decreased as the speed of contraction increased. This characteristic of skeletal muscle was also supported by most exercise physiologists (Bell et al., 1989).

Peak Torque

Research has defined peak torque as the highest point achieved on the torque vs joint angle curve (Lesmes et al., 1978; Coyle et al., 1981; Bell et al., 1989).

Resistance training at slow velocities has been shown to increase knee extension torque and power improvements and to be greatest at slow angular velocities but with increases in peak torque transferring to faster velocities (Caiozzo et al., 1981); Kaneshisa and Miyashita, 1983; Petersen et al., 1988).

Resistance training at an intermediate velocity has produced conflicting results (Bell and Wenger, 1992). Some research has suggested that the training effect was specific only to the training velocity (3.14 $rad \cdot sec^{-1}$) with no evidence of transfer to other velocities (Petersen et al., 1984). Bell and Wenger (1992) maintained the majority of research suggested that resistance training at an intermediate velocity resulted in transfer of training effect to slow (Lesmes et al., 1978) as well as fast velocities (Andyanju et al., 1983; Kanehisa and Miyashita, 1983; Timm, 1987; Bell et al., 1989). Timm (1987) recently investigated this transfer of training effect, or "overflow" to other velocities. He found that the training effect representing peak torque transferred by a magnitude of $\pm$ 2.09 $rad \cdot sec^{-1}$ for knee extension and knee flexion.

Resistance training at a fast velocity has also produced some controversy in the literature with respect to velocity specific adaptation. Most of the research has suggested that gains resulting from fast velocity training were seen most prominently at fast angular velocities (Caiozzo et al., 1981; Smith and Melton, 1981). Other researchers (Dudley and Djamil, 1985; Coyle et al., 1981) have shown that training at 4.19 $rad \cdot sec^{-1}$ produced increases in torque in slow velocities and fast velocities equally.

Most of the research has suggested that maximum gains in torque after training at slow or fast angular velocities occured at or near the training velocity with some transfer to other angular velocities near the trained velocity (Bell and Wenger, 1992). The intermediate velocity seemed to allow for most of the transfer effect. Bell and Wenger (1992) indicated that specificity or non-specificity of velocity in velocity controlled resistance training could be a function of the muscle groups tested. Kanehisa and Miyashita (1983) demonstrated that elbow flexors responded to intermediate velocity training which produced more notable increases with light loads while slow velocity training produced more notable increases while training with heavy loads. Bell et al. (1988), and Petersen (1984) have shown that greater relative peak torque increases in the knee flexors compared with the extensors following intermediate velocity training. Finally, Garnica (1988) demonstrated that shoulder extension/flexion has a greater transfer from slow velocity training to intermediate velocities than intermediate to slow velocities. Garnica (1988) cited that this pattern of transfer differed from that of the knee extensor/flexors.

The literature has supported the notion of velocity specificity in training, as peak torque at slow velocities was greatest in response to slow velocity training, and peak torque at fast velocities was maximized when training at fast velocities. Intermediate velocity training appeared to produce increases at both slow and fast velocities but not to the same extent as specifically training slow or fast velocities exclusively (Bell and Wenger, 1992). However, Bell and Wenger (1992) suggested that the transfer effect from intermediate velocity training could be applicable to individuals who participated in sports that require various velocities of movement.

Neuromuscular Adaptation

Researchers have determined that adaptation within the nervous system was a result of resistance training (Moritani and DeVries, 1979; Hakkinen and Komi, 1983). These so called "neural" adaptations have generally had the greatest influence on muscular strength within the first three to five weeks of resistance training. Characteristics of the neural adaptation are: increased motor unit excitability; enhanced motor unit synchronization; and decreased twitch tension and contraction (Milner-Brown et al., 1975, Sale et al.,1982, 1983, 1988). Bell and Wenger (1992) stated that very little research had investigated the actual neural components responsible for velocity controlled adaptations. Perrine and Edgerton (1978) hypothesized that a tension-limiting mechanism existed within the muscles or tendons which may be preferably altered with different training velocities. It was suggested that slow velocity training may "reset" this neural mechanism which would cause decreased neural inhibition and enhanced force production. Behm and Sale (1993) reinforced the notion that neural as well as muscular adaptation played a role in the high velocity training response. Neural adaptation may have involved selective activation of motor units and or muscles and increased synchronization of motor units. Additionally, the training response was composed so that the ensuing contraction of the muscle throughout the full range of motion is not necessary. Behm and Sale (1993) cited the key stimuli for velocity specific training response was the motor command and the characteristic motor unit activation pattern associated with a high velocity movement along with the high rate of force development of the ensuing contraction.

It has appeared that adaptation of the nervous system to velocity controlled resistance training played a large role in the acquisition of muscular strength especially within the first three to five weeks of a training program (Bell and Wenger,1992).

Hypertrophy

Hypertrophy characterized by an increase in the diameter of an individual muscle fibre (Brandy et al., 1990) is a well documented result of traditional resistance training programs. In velocity controlled resistance training hypertrophy due to slow or fast velocity training is not well documented (Bell and Wenger 1992). Some researchers have shown increases in fast twitch muscle fibre area as a result of intermediate and fast velocity resistance training, but, no significant findings of hypertrophy were found due to slow velocity training (Costill et al.,1979; Coyle et al., 1981; Petersen et al., 1989). Sale (1988) and Bell and Wenger (1992) postulated that this could be because intermediate and fast velocity training produced greater recruitment of fast twitch motor units since the contractability of slow twitch motor units to the generation of force decreased as the contraction time increased. It could also be because the training programs for slow velocity training may not have been studied in sufficient length to stimulate muscle hypertrophy. As seen in other studies, significant hypertrophy of the slow muscle fibres may take eight to ten weeks to be appropriately stimulated. Jansson et al. (1990) reported some evidence of velocity specific fibre type alterations and increases in the proportion of type I (9%) and type IIA (6%) fibres after a 4 to 6 weeks sprint training program. Jansson et al. (1990) attributed this alteration to a changed pattern of muscle fibre activation which could have induced the increased synthesis of type II fibre myosin.

Summary

Velocity controlled resistance training on instruments such as the Cybex II has produced many advantages, including: precise control of movement velocity; range of motion being fixed as desired; no external load placed upon the individual; and maximal volitional movement having met with maximal resistance throughout the range of motion, training strength maximally at all joint angles (Bell and Wenger, 1992). The main point was that velocity controlled machines such as the Cybex II (with the exception of the Kincom) involved only concentric muscle contractions on both sides of the limb. Armstrong (1984) maintained that concentric exercise led to less muscle soreness and damage than eccentric exercise training.

Velocity controlled resistance training could be an effective, safe method to increased muscular strength power and endurance. It could also result in adaptation in peak torque, hypertrophic, and neuromuscular parameters. The majority of research has shown velocity specific acquisitions of peak torque at a slow and fast training velocity. Training at an intermediate velocity has appeared to result in an "overflow" of training effect to both high and low velocity as well as the training velocity (Bell and Wenger, 1992).

PHYSIOLOGICAL EFFECTS OF DETRAINING

Detraining has been described as a process wherein occurs a reversal of the physiological effects due to a training program when training is terminated. Detraining in resistance training literature has documented a consistent decline in strength measures following cessation of a training program. Generally, the rate at which this decline took place was usually less or comparable to the rate at which the strength had increased during the training program (Collinder & Tesch, 1991; Dudley et al., 1991; Hakkinen, 1985; Hakkinen & Komi, 1983; Houston et al., 1983; Narici et al., 1989; Staron et al., 1991; Thorstesson, 1977). It has been shown that detraining caused a significant reversal of the strength induced neural (increased motor unit synchronization and activation) and muscular (hypertrophy, increased content of creatine phosphate) adaptations, although not necessarily to pretraining levels (Cote et al., 1988; Staron et al., 1991). With regard to changes in neural factors during detraining, Hakkinen and Komi (1983) and Narici et al (1989) observed significant decreases in integrated EMG; also, Milner-Brown (1977) reported decreases in synchronization of the motor units within the first 4-6 weeks of detraining. Muscular factors have also been shown to decrease at a similar or lower rate than corresponding decrease in strength measures (Collinder and Tesch, 1991). Adaptations to the muscle from detraining have included decreased muscle fiber cross sectional area as well as muscle size, fiber type size and fiber type area (Hakkinen 1981, 1985; Staron et al., 1991; Narici et al., 1989).

In the literature, documentation has primarily focused on isotonic resistance training. Only a few studies have researched the effects of detraining following velocity controlled resistance training. Of those, two utilized a slow velocity of training 90 deg$\cdot$sec^{-1} and 60 deg$\cdot$sec^{-1} in Cote et al. (1988) and Collinder and Tesch (1992); the other used a intermediate velocity (120 deg$\cdot$sec^{-1})(Narici et al., 1989). Studies which used the slow velocities of training noted that the peak torque values declined with detraining but did not return to the pretraining levels. After 12 weeks of detraining Collinder and Tesch (1992) documented a retained increase of 12% for their concentric training group and 18% for the combined eccentric and concentric training group. Cote et al. (1988) demonstrated only a 12% decline in torque values following their detraining period. Although this was considered significant, it was less than the values of Collinder and Tesch (1992) primarily due to a relatively short duration of detraining. Both groups of researchers attributed the retention in torque to neurological factors due to the absence of hypertrophy following the training program for either the concentric or the combined training group. Narici et al. (1989) studied the intermediate velocity resistance training on subjects who trained for eight weeks and detrained for only six weeks. They found that the kinetics of changes in cross sectional area and neural drive during training and detraining were similar. The performance measures declined at a similar rate as they were gained; however, only isometric maximal voluntary contraction was measured following the detraining period.

In light of the research described it was obvious that physiological measures such as peak torque and isometric maximal voluntary contraction declined at a lower or similar rate gained when training ceased. Over relatively short detraining periods (eight-12 weeks) physiological measures both neurally and muscularly decreased significantly but often times not entirely to pretraining values (Staron et al., 1991). Detraining studies were found to be quite scarce in the literature, and even more scarce were those which have used velocity controlled resistance training. There did not appear to be available a study which utilized fast velocity controlled resistance training; therefore, studies are required which document the effects of detraining on physiological variables following a fast velocity controlled resistance training program.

PHYSIOLOGICAL ADAPTATION OF INDIVIDUALS WITH CEREBRAL PALSY TO RESISTANCE TRAINING

Resistance training has been used by individuals with cerebral palsy (CP) to increase strength and improve their athletic performance. Only a handful of studies however, have examined the effects of progressive resistance exercise in individuals with CP.

Assessment of muscular strength and endurance in persons with cerebral palsy has been somewhat controversial (McCubbin, 1994). Bobath (1971) indicated that muscular strength was not the motor problem in individuals with cerebral palsy and therefore was not to be an area for testing and training. In addition, Bobath (1971) has cautioned that progressive resistance training may cause abnormal flexion and muscular tone in CP individuals and further recommended caution in prescribing resistance training to individuals with CP.

Researchers have shown that progressive resistance exercise did promote strength gains in individuals with CP through resistance training. Early studies by Healy (1957) and Meditch (1961) indicated that it was possible to increase the strength of individuals with CP through isotonic resistance training. Horvat (1987) found that a program of progressive resistance exercise was beneficial for improvement of motor performance in a individual with mild spastic hemiplegia. Improvements were found in torque production of strength (one repetition at 60 rpm), endurance (15 repetition at 180 rpm) and range of motion.

Holland and Steadward (1990) recently addressed the issue of resistance training and spasticity/muscle tone. They discovered that strength training coupled with flexibility exercise did not appear to produce any detrimental effects in muscle tone and in fact, improved flexibility and range of motion. In their study, three physical therapists qualitatively analyzed the gait of their subjects utilizing videotape three times during the study (Pre-Interim-Post training) to determine if there were any decrements in motor performance due to the resistance training.

Previous research cited that muscular conditioning produced a decrease in the ratio of the H-reflex to the motor action potential (Shepard, 1990; Spira, 1967, 1974). The H-reflex served as a measure of spasticity while direct motor action potential represented all active motor neurons. Descriptions of improvement as a result of resistance training was noted in a few studies, those of Meditch (1961), Horvat, (1987), and Holland and Steadward (1990); however the method of adaptation within the body both muscularly and neuromuscularly has not been thoroughly investigated.

An important component of normal functional activity and sport is the ability to perform alternating contractions such as walking, running, cycling, swimming, and climbing stairs (Watkins et al., 1984). This performance was significantly altered in individuals with cerebral palsy (Leonard et al., 1990; Milner-Brown,1979 Parker et al., 1992; Watkins et al., 1984). It has been well-documented that individuals with CP have spinal and supraspinal reciprocal inhibition/facilitation which were responsible for low muscular coordination during voluntary movement in which individuals excessively coactivate antagonist muscles during movement (Parker et al., 1992; Leonard et al., 1990; Nielson et al., 1990; Milner Brown, 1979). Damage to the brain in CP has been shown to disrupt the ratio of excitatory and inhibitory impulses from the afferent nerves, causing cocontraction of the agonist and antagonist muscles. As a result of this altered agonist/antagonist relationship performance, deficits in terms of movement velocity and muscular force were attributed to the exaggerated reflexes and failure of the reciprocal inhibitory/facilitory relationship, prolonged recruitment and delayed cessation of the agonist and impaired type II motor unit recruitment in the agonist muscle (El-Abod et al., 1993; Watkins et al., 1984; Sahrmann and Norton, 1977). All of these factors have made it difficult for spastic and athetotic patients to complete reciprocal contractions, particularly at a fast velocity (El-Abod et al., 1993; Watkins et al, 1984; Parker et al. 1992; McCubbin and Shasby, 1985). Methods to enhance this reciprocal relationship are needed. It has been shown in the non-disabled population that cocontraction and reciprocal inhibition were positively altered by training as evidenced through improved motor function and less cocontraction with repetitive practice trials (Hobart, Kelley & Bradley, 1975; Koltke, 1980; Payton & Kelly, 1972; Person, 1958; Cirello, 1982; & Kaman, 1983).

Accurate quantification of motor performance had to comply with resistance training programs and studies in order to properly document the effectiveness of various training regimes. Recent research by Holland et al. (1994) was conducted to improve the quantification of muscular strength and endurance by studying the reliability of velocity controlled concentric and eccentric muscle testing of adults with cerebral palsy. Fourteen subjects were tested on shoulder abduction and adduction as well as knee flexion/extension at 60 degrees per second. It was determined that the Kin-Com appeared to be a reliable testing tool for the collection of maximum torque values for the knee flexors and extensors along with the shoulder abductors and adductors in persons with CP following at least one introductory session. Consistency could not be obtained when average torque values were determined for eccentric knee extension and concentric knee flexion. Higher velocities were not tested in this study which brings to question the reliability of the muscular strength and endurance measures at the intermediate and fast velocities of training.

Adaptations of individuals with CP to velocity controlled resistance training has been noted in only two previous studies: McCubbin and Shasby (1985) and McCubbin (1994). The authors stated that as CP results in inefficient muscular contractions, this may explain the inefficient application of strength and speed of movement; techniques for enhancing this inefficient application of strength and speed need to be studied.

McCubbin and Shasby (1985) used a six week isokinetic resistive exercise program for the elbow flexors and extensors to show that the subjects with CP, when trained isokinetically, increased peak torque and rate of torque development significantly within the first three weeks and following six weeks of Isokinetic training. This suggested that neurological adaptation is the determining factor of this substantial change within the first three weeks of resistance training, a factor also observed in the non-disabled population. McCubbin and Shasby (1985) noted that for individuals with CP this neurological adaptation may have resulted from several important neural mechanisms. Synchronization of motor units may have occurred in these subjects, as characterized by an increased ability to simultaneously contract a larger number of motor units. This resulted in an increased torque production which in turn escalated the rate of force development (McCubbin and Shasby, 1985). Another important neural mechanism was reciprocal inhibition which is the relationship between the contracting agonist and the relaxing antagonist muscle. McCubbin and Shasby (1985) hypothesized that the improvement in peak torque and speed of movement in their study may have been an improvement of the reciprocal inhibitory mechanism, although no direct measurement of muscle cocontraction or neural activation was undertaken.

The limitation of McCubbin and Shasby's (1985) study was that subjects were only tested and trained at one angular velocity; therefore, specificity of this improvement in peak torque was not determined and no direct investigation was used to decipher the mechanisms responsible for the observed improvements in muscular performance. McCubbin (1994) followed up his original work which expanded upon the previous research by utilizing different training devises and by training arms and legs bilaterally. Data was collected on 24 adolescents and young adults (13 experimental, 11 controlled) with varying degrees of cerebral palsy. Subjects underwent six weeks of training on a Total Power device from Hydra-Fitness Industries. During each exercise session subjects completed six sets of ten maximal repetitions in both chest press and knee extension, three sets of ten at a resistance setting approximating 60 degrees per second and three sets of ten at a resistance setting approximating 120 degrees per second. Subjects trained three times per week and results indicated that the hydraulic resistance exercise could improve muscular strength measures as determined by increases in peak torque in the experimental group. Other significant findings included positive changes in peak torque recruitment time, or the time it took for the subject to accelerate to peak torque as a result of the training program. The latter finding had a stronger effect than for that of improved peak torque. McCubbin (1994) postulated that there was definitely potential for more efficient recruitment of muscle fibres for the given action. McCubbin (1994) also supported the findings of Holland and Steadward (1990) which indicated that individuals with CP can undergo a resistive exercise program without any decrements in range of motion due to spasticity or other deleterious effects.

The evidence presented by McCubbin and Shasby (1985) and McCubbin (1994) have important implications for further study. It was documented that individuals with CP involved in sport did exhibit increased in performance in all sports due to training, and suggested also that there appeared to be no deleterious effects as a result of the training programs for individuals with cerebral palsy. Those factors which acted to increase performance whether it was increased global neural activation, muscle hypertrophy, increased mechanical efficiency, or improved coordination through decreases in reciprocal inhibition/facilitation and cocontraction during voluntary movement, have yet to be demonstrated. In light of this observation, research is required into, 1) the effects of faster velocities of training in the acquisition of improved muscle performance, as methods of training were based on the specific response of the muscular system to training; and, 2) the nature of the improvement of important neuromuscular properties of individuals with CP, optimistically to improve muscular function and performance of individuals with CP.

Summary

Research conducted in the non-disabled population in terms of velocity controlled resistance training, indicated a definite velocity specific adaptation to slow and fast velocity training. This, therefore, demonstrates tremendous implications to the planning of sport specific training. Individuals with CP showed improvements in peak torque, time to peak torque and speed of movement a result of training at a slow and intermediate velocity which appeared to indicate some improvements of the neurological mechanisms which may ahve limited their efficiency of volitional movement without any negative effects; however, limited information is currently available. It became apparent that further studies were warranted in order to determine if individuals with CP can improve their muscle function through measurement of various parameters following velocity controlled resistance training programs, despite their evident neurological condition.

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CHAPTER III
METHODOLOGY

Sample Selection

Subjects were selected according to the following criteria:

1. They were male or female with cerebral palsy between the ages of 12 to 60.
2. They were able to complete the required testing and training speeds.
3. They did not have any medical contraindication that would have prevented them from participating in the study.
4. They were required to comprehend and sign the informed consent.

Table 3-1. Subject Characteristics

SUBJECT	SEX	AGE (yrs)	HEIGHT (cm)	WEIGHT (kg)	TYPE OF CP	CP-ISRA CLASS
1	M	12	165	54.4	Diplegia	8
2	F	30	154	55	Rt Hemiplegia	7
3	M	35	177	68	Diplegia	5
4	F	24	157	47	Lt Hemiplegia	7
5	M	29	178	70	Quadriplegia	5

A decision was made to include an adolescent in the study due to lack of availability of a more suitable subject.

All subjects were screened by a physician prior to participation in the study to ensure there was no contraindication to training (ie. recent injury or medications that may have altered their response to the training program)

Subjects who had been previously classified according to the CP-ISRA classification system were #1, #2 and #4. As there were insufficient Alberta-based classifiers available the others (subjects #3 and #5) who were to be classified prior to the commencement of the study were categorized by the primary researcher in order that some meaningful generalizations could be made to the particular classes identified following analysis of the results. The functional characteristics of the CP-ISRA classification system for Classes 5, 7, and 8 are outlined in Appendix A.

The subjects were recruited through personal affiliations and referrals from the Rick Hansen Centre, The Alberta Cerebral Palsy Sports Association, and the Cerebral Palsy Association of Alberta.

Subjects were not offered incentives to participate in the study other than improved well-being, knowledge of their own bodies and some resistance training advise. Subjects signed an informed consent (parent or guardian in one case). The study was approved by the University of Alberta Faculty of Physical Education and Research Ethics Committee.

Procedures

Research Design

The research design utilized in this study was an ABA single subject, multiple baseline across subjects design. Traditional designs of homogeneous experimental and control groups were rejected due to the high intersubject and intrasubject variability. Five subjects completed four baseline measures during the baseline phase (A1) of the study, tnen were randomly assigned to one of five baselines in which the intervention (B) points were spaced one week apart. Following the start of the training program, each subject was to be tested every two weeks through the eight weeks of the training program, then through the ten weeks of the withdrawal phase (A2). The withdrawal phase (A2) was added to the design to provide additional strength to the study in an attempt to establish the effect of the treatment by watching it decay with time and lack of training. Due to time constraints and availability that could have affected participation in the study subject 1 requested to train first; therefore, subject 1 could not be assigned randomly to one of the five baselines. An illustration of the experimental design is provided in Figure 3-1.

Figure 3-1. Experimental Design

```
                              Experimental Design
WEEKS 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 24
B1 A1  ****B  *   *   *    *A2   *     *      *     *    *
B2 A1  **** B   *   *   *    *A2   *     *      *     *    *
B3 A1  ****    *B  *   *   *    *A2   *     *      *     *    *
B4 A1  ****      *B  *   *   *    *A2   *     *      *     *    *
B5 A1  ****        *B  *   *     *    *A2   *     *     *    *    *
```

B - Baseline number

* - evaluation of all dependent measures

All points between A1 and B are measures in the baseline phase of the study

All points between B and A2 are measures during the intervention phase of the study

All points following A2 are measures in the withdrawal phase of the study

Instrumentation

The dependent variables of interest in this study were peak torque (PT), average power (AP), total work (TW), and torque acceleration energy (TAE) by completing maximal contractions at each of the six specified angular velocities (in $rad \cdot sec^{-1}$, 0.52, 1.05, 2.09, 3.14, 4.19, 5.24), and muscular endurance, determined by completing 25 maximal reciprocal contractions at an angular velocity of 3.14 $rad \cdot sec^{-1}$.

The instrument used for the data collection and training of the subjects was the Cybex 340 Isokinetic Dynamometer (Lumex, Inc. New York, USA). The Cybex 340 Dynamometer allowed the measurement of PT, AP, TW, and TAE produced by dynamic muscular contraction through computerized analysis, while the velocity of movement was controlled and maintained constant. The device applied an accommodating resistance when the subject accelerated to the preset velocity. The Cybex 340 Isokinetic Dynamometer utilized a integrated computer that simultaneously recorded all torque (foot-pounds) and joint angle and calculated all power and work measurements. Malone (1988) reinforced that there was no change in the mechanical aspects of the Cybex 340 from that of the Cybex II, thus, the same accuracy and reliability was expected as in past studies of the Cybex II (Bemben et al., 1988; Murray et al., 1986; Perrine, 1986; Sinacore et al., 1983; Taylor and Casey, 1986). The Cybex 340 was investigated to determine its mechanical and physiological reliability, and technical accuracy (Timm et al., 1992). Timm et al. (1992) determined that the technical and mechanical measurement reliability of the Cybex 340 was excellent with ICC's above 0.90. Physiological reliability determined for PT, AP, and TW was generally high at the slower to intermediate velocities of testing (ICC's above 0.90) but at the faster angular velocities decreased especially at 300 deg. sec-1 for both the knee extensors and flexors (ICC's between 0.68-0.79). TW tended to be the least reliable at the faster speeds for the extensors as well as TW and AP for the knee flexors. Timm et al. (1992) attributed the decreasing physiological reliability to variability in the subjects' performance in light of the high mechanical and technical accuracy at all testing speeds. Factors considered during physiological testing were nutritional status, systemic fatigue, and motor learning (Timm et al., 1992).

For this study the damping setting was automatically set by the computer to be maintained constant for all measures in order to keep the interpretation of the results consistent within the same person's results.

Testing

All of the subjects were tested on knee extension and knee flexion by the Cybex 340 Isokinetic Dynamometer at six angular velocities (in rad sec^{-1}, 0.52, 1.05, 2.09, 3.14, 4.19, 5.24). The results were recorded by the Cybex 340 integrated computer for all angular velocities tested. The testing procedures to be outlined were repeated for each session of testing throughout the experiment. The results were corrected for gravitational influences by the on-line computer to ensure a more accurate measurement of the actual torques being exerted. This method required recording the gravitational torque generated by the weight of the limb-lever arm falling at a specific angular velocity from the anatomical 0 degrees position through to the 90 degrees range of movement. During this procedure, subjects did not have difficulty relaxing sufficiently to allow the lever arm to drop consistently when tested each time.

Calibration of the dynamometer was conducted prior to each testing session using the procedures outlined by the manufacturers. Subjects were seated on the dynamometer with their upper body immobilized with chest, waist, and thigh straps in an attempt to isolate the knee extensors and flexors. Seat angle was set at 85 degrees. The input axis of the dynamometer was visually aligned with the rotational axis of the knee on the first testing occasion and the position of the seat, and the height of the dynamometer was recorded to reproduce the same conditions for each testing session. The lever arm was secured to the tibia one centimetre proximal to the ankle malleoli. The tests began with the knee in the flexed position. Range of motion designated for measurement was 80 degrees of the knee joint from a fully flexed position as the diplegia subjects had difficulty reaching full knee extension due to tight and spastic hamstrings.

Subjects were instructed to exert a maximal effort through their available full range of motion for both extension and flexion of the knee joint. PT, AP, TW and TAE were determined from four continuous maximal repetitions at 3.14, 4.19, and 5.24 rad·sec^{-1}. The number of repetitions was decreased to three at 0.52, 1.05, and 2.09 rad·sec^{-1} to reduce fatigue as a result of testing a number of angular velocities. Adequate rest (approximately 3 minutes) was given between each test at each angular velocity. The order of testing velocities was randomly assigned prior to the start of the study and kept constant for the duration of the study. Subjects were also verbally encouraged to give maximal efforts throughout all testing sessions. Subjects were able to view their torque and work per repetition by observing the on-line computer monitor which gave them visual feedback to achieve the highest reading possible for each contraction.

The muscular endurance test was completed following a four-minute rest after measurement at the six angular velocities. The subjects were secured to the Cybex 340 as previously described and instructed to complete 25 maximal repetitions at a angular velocity of 3.14 rad·sec^{-1}. The subjects were verbally encouraged throughout the entire test to give maximal effort to each contraction. This test was chosen as it has been used reliably in previous research in the non-disabled population (Burdett and Swearigan, 1987; Montgomery et al., 1989). Measures of absolute endurance were expressed as total work (TWE), and average power (APE). Relative endurance or fatigability, was expressed as the percent fatigue (PFE) in performance, a percentage of initial peak torque values. The PFE was calculated by the Cybex 340 computer by averaging the knee extension and respective knee flexion peak torque values from the first five repetitions, and the average peak torque values from the last five repetitions. The PFE calculated by the computer was expressed as the percentage of the last five torque values compared to the first torque values representing 100 percent. The percentage obtained from the computer was recalculated to PFE by subtracting the computer number from 100. The velocity of 3.14 $rad \cdot sec^{-1}$ was chosen because of its reported reliability when compared to other velocities for an endurance test and its frequent use for endurance testing (Burdett & Swearigen, 1987; Montgomery et al, 1989). In addition, 3.14 $rad \cdot sec^{-1}$ is not a velocity being trained in this study.

During the entire study, the following testing protocol was strictly adhered to:

At angular velocities of 3.14, 4.19, and 5.24 $rad \cdot sec^{-1}$ the subjects were given two practice maximal repetitions followed by one minute rest; they then completed four continuous maximal repetitions from which the dependent variables were determined. At angular velocities 0.52, 1.05, and 2.09 $rad \cdot sec^{-1}$ subjects were given one practice maximal repetition followed by one minute rest; they then completed three continuous maximal repetitions from which the dependent variables were determined. This protocol was chosen in order to decrease a portion of the practice effect possibly observed in the initial testing phase. Providing practice repetitions enabled the subjects to sense the actual task to be completed and provided the researcher with an opportunity to provide appropriate feedback to the subject ensuring the task was performed to the best of the subject's ability.

Maximal practice repetitions also provided a standardized test procedure whereby defining submaximal practice repetitions was not essential.

The muscular endurance test was completed, as described above following four minutes rest after the assessment at the six angular velocities. Each subject was given two maximal practice repetitions followed by a one-minute rest, then 25 maximal repetitions, from which the dependent measures were calculated.

The protocol was performed on three separate testing days with no fewer than 48 hours and no more than 96 hours rest between consecutive testing sessions. Attempts were made to test each subject at the same time of the day during each testing session. The same examiner tested all subjects on each day.

Establishment of the Baseline

The consistency of all of the dependent measures in the baseline was analyzed through calculating the absolute reliability of the baseline measures by obtaining the standard error of measurement (SEM) which were an important measurement as it estimated the precision of the measurements obtained (Rowley, 1989). Calculating the SEM helped the primary researcher to differentiate absolute changes from irrelevant fluctuations by the calculation of the 95% confidence ranges about the mean phase measurement. Any subsequent measurement outside the range was assumed to be absolute change (Gajdosik and Bahannon, 1987; Rothstien, 1985). The SEM was used to interpret subjects' values in order to determine whether differences between tests and phases were due to true change or error. The SEM was calculated by obtaining the standard deviation of each individual scores for all dependent measures, for both the dominant and non-dominant legs, across three baseline tests for subjects 1 and 2; across four baseline tests for subjects 3, 4, and 5. The obtained standard deviations for the dominant and non-dominant sides of each subject on each dependent variable were then averaged to calculate the SEM for the dominant and non-dominant sides (Rowley, 1989). The resultant SEM's are displayed in Table 3-2.

The subjects were tested on three initial occasions; they then completed an additional test one week following the third test. All subjects were tested by the

Table 3-2. Standard Errors of Measurement for all Dependent Meaures of Knee Flexion and Extension

	KNEE FLEXION		KNEE EXTENSION	
Peak Torque (ft. lbs.)				
Speed (rad.sec-1)	**Dominant**	**Non-Dominant**	**Dominant**	**Non-Dominant**
0.52	4.42	3.78	5.48	6.46
1.05	3.62	3.49	6.65	6.20
2.09	2.85	4.36	7.10	5.02
3.14	2.10	3.14	4.77	6.93
4.19	3.36	2.99	4.05	4.98
5.24	3.32	3.66	3.54	4.09
Average Power (Watts)				
Speed (rad.sec-1)	**Dominant**	**Non-Dominant**	**Dominant**	**Non-Dominant**
0.52	2.33	1.51	2.47	2.47
1.05	2.14	3.55	5.97	5.29
2.09	5.23	7.26	12.01	10.30
3.14	5.30	8.37	14.43	12.11
4.19	12.36	11.00	18.17	18.90
5.24	11.67	18.82	23.16	19.41
Total Work (ft. lbs.)				
Speed (rad.sec-1)	**Dominant**	**Non-Dominant**	**Dominant**	**Non-Dominant**
0.52	3.84	2.67	5.38	4.74
1.05	3.15	3.90	5.60	5.52
2.09	5.49	7.53	6.69	3.78
3.14	2.59	3.10	5.35	5.31
4.19	3.53	3.34	4.72	5.63
5.24	3.03	4.13	3.63	4.54
Torque Acceleration Energy (ft. lbs.)				
Speed (rad.sec-1)	**Dominant**	**Non-Dominant**	**Dominant**	**Non-Dominant**
0.52	0.12	0.14	0.22	0.17
1.05	0.26	0.15	0.40	0.26
2.09	0.36	0.51	0.80	0.86
3.14	0.71	1.26	1.15	0.99
4.19	0.70	1.19	2.22	1.21
5.24	0.85	1.19	2.02	1.63
Average Power Endurance Test (Watts)				
Speed (rad.sec-1)	**Dominant**	**Non-Dominant**	**Dominant**	**Non-Dominant**
3.14	5.55	5.48	9.05	10.03
Total Work Endurance Test (ft. lbs.)				
3.14	43.34	47.03	74.28	78.70
Percent Fatigue Endurance Test (Percent)				
3.14	8.83	8.37	8.68	12.67

primary researcher. Standardization of the testing conditions was adhered to as strictly as possible for all testing sessions. The legs of tested subjects were categorized into dominant and non-dominant by evaluating the peak torque results at all speeds in flexion and extension to see which limb had the overall higher peak torque at 0.52 rad·sec^{-1}, the limb with the higher peak torque was identified as the dominant side and the one with the lower overall peak torque was identified as the non-dominant side. Subjects were also asked whether they had a preferred or more dominant side to help categorize the sides and see if the peak torque measures were consistent with their personal reports. The dominant and non-dominant sides were considered the "less involved" and "more involved" sides, respectively. The match of the personal reports to the torque vales analysis was consistent for both flexion and extension for all subjects, with the exception of subject #3 whose dominant side in flexion was the right and in extension, the left. It was subsequently decided that the right side was the dominant side, from the flexion scores and his personal reports. Subject #1 showed right dominance in flexion and left dominance in extension. Subject #1's left side was selected as the dominant side based on his personal reports. The categorization was completed in order to group the individual results into meaningful categories for the analysis of baseline consistency, and the results.

Training Program

During the intervention phase subjects concentrically trained the knee extensors and flexors in the same manner as the testing procedure, by using the Cybex 340 Isokinetic Dynamometer. Subjects exercised three days per week, completing sets of 20 maximal continuous repetitions with two minutes rest between sets. Each subject was progressively overloaded as outlined in figure 3-2. Selection of this training program was based on previous research where significant gains in fast velocity peak torque and power measures were noted; 20 repetitions was effective for seeing changes in PT, AP, and TW (Davies et al., 1986; Jenkins et al., 1984; Kanehisa and Miyashita, 1983; Perrin et al.,1989). The training program during the intervention phase was eight weeks in duration.

Figure 3-2. Method of Progressive Overload

WEEKS OF TRAINING PROGRAM	Sets of 20 Repetitions
0-2	2 SETS
2-4	3 SETS
4-8	4 SETS

Withdrawal Phase

Following the training program subjects withdrew from the treatment for 10 weeks to observe any decay in training effect. The subjects were instructed not to increase their activities during this phase and not to undergo any other forms of training. During this phase the subjects were to be tested every two weeks for a total of five sessions to see what effects occurred when the treatment was withdrawn. Due to scheduling problems and holidays, subjects 1 and 4 participated only in four tests during the withdrawal phase.

Method of Analysis

All dependent measures were analyzed visually as well as through calculating the mean performance during the baseline phase (A1), the intervention phase (B), and the withdrawal phase (A2). The mean performance scores for each of the phases were calculated as follows:

The baseline phase means were calculated by adding up the performance scores from tests 2, 3, 4 then dividing the resultant score by the number of tests for subjects #1 and #2; and by adding the performance scores from the tests 2, 3, 4, 5, then dividing the resultant score by the number of tests for subjects #3, #4, and #5. The first test for all subjects in the baseline phase on all dependent measures, was removed from all the graphs and the calculations of the standard error of measurements. This data point was removed as it reflected the familiarization of the subjects to the testing procedure. With the removal of this data point both graphically and numerically the trend and calculations of the subjects was more representative of the changes which occurred.

The intervention phase means were calculated by the same method as in the baseline phase except that the scores on tests 3, and 4 of the intervention phase were used. The first and second tests of the intervention phase were removed from the calculations to get a better representation of the performance which occurred in that phase.

The withdrawal phase means were calculated using the same method as the baseline and intervention phases except that the scores on tests 3, and 4 were used for subjects #1 and #2; and the scores on tests 4, and 5 were used for subjects #3, #4, #5. The first and second tests of the withdrawal phase were removed from the calculations to get a better representation of the performance which occurred in that phase.

Percent change across phases was calculated for each phase of each dependent measure. Percent change from phase A1 to B was calculated by subtracting the mean value of (A1) from the mean value of (B) then dividing the resultant score by the mean value of (A1) and multiplying by 100. Percent change from phase B to A2 was calculated by subtracting the mean value of (A2) from the mean value of (B) then dividing the resultant score by the mean value of (B) and multiplying by 100. Percent change from phase A1 to A2 was calculated by subtracting the mean value of (A2) from the mean value of (A1) then dividing the resultant score by the mean value of (A1) and multiplying by 100. The scores from these calculations were either positive or negative which indicated the direction of the change across phases. The percent change scores across phases were used in conjunction with the graphical data and evaluation of the SEM confidence interval around the baseline mean scores, to analyze any absolute changes across phases by looking at the consistency between the percent changes and the trends of the graphical data.

The standard error of measurement values was used to calculate a confidence interval by adding and subtracting two SEM values above and below the baseline phase means, from which to judge whether absolute change occurred as a result of the intervention or whether the effect was due to random error. A measure was judged to be significant, and a result of the treatment recognized, under the following conditions: 1) If the difference between the means of the baseline and the intervention was greater than plus two SEM for any of the following measures, PT, AP, TW, TAE, TWE, and APE; and less than minus two SEM for PFE; 2) If the graphical data showed sloping trends during the intervention which were visually different from the baseline data points and were consistent with the SEM analysis. Withdrawal phase values were significant if the graphical data showed a decay of the measurements back toward baseline values which were in the opposite direction of the intervention phase data points.

Figure 3-3. Illustration of Procedures

Subject physician screen

Subject orientation and informed consent

Stability testing

Random assignment to starting baseline
for the fast velocity controlled training program

Start training program at assigned baseline

Interim Test 1

Interim Test 2

Interim test 3

Finish training program

Post test

Start withdrawal phase

Withdrawal test 1

Withdrawal test 2

Withdrawal test 3

Withdrawal test 4

Withdrawal test 5

Data Analysis

Summary of Results

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CHAPTER IV
RESULTS AND DISCUSSION

Introduction

Individual results will be , ~~sented which include PT, AP, TW and TAE of both knee flexion and knee extension through the six angular velocities on the Cybex. In addition, changes in TWE, APE and PFE will be provided. This will be followed by a discussion of the findings. At the end of the chapter there will be a general discussion summarizing the data with some recommendations and conclusions.

1.INDIVIDUAL R. LTS

SUBJECT #1

Subject Characteristics

Subject #1, a 12 year old male was referred to the study by his coach who thought it would be beneficial for him to be involved in an organized resistance training program. Parental consent was obtained for subject #1 to participate in the study. Subject #1 was very eager to participate in the study as he has been involved in the swimming program through the Alberta Cerebral Palsy Sports Association for the past two years. Prior to the study, he was swimming two to three times per week preparing for upcoming competitions. It was confirmed with him and his coach that participation in the study would not interfere with his current training and that his exercise volume and current intensity would not change significantly over the duration of the study.

Subject #1, was also a class eight swimmer who had diplegia and ambulated well without the use of any assistive devises. His lower limbs were the most involved and were categorized as R-ND and L-D.

On initial testing subject #1 was given a 15-minute orientation and demonstration of the movements and effort that were expected from him when he performed the tests on the Cybex 340. On initial assessment subject #1 had to be given instruction to continue to exert a maximal effort on all tests. He comprehended the instructions well and gave forth his best efforts. Subject #1 found the slow testing speeds the most challenging as it was difficult for him to stay motivated in order to produce a maximal effort over three muscular contractions especially at 0.52 rad$\cdot$sec^{-1} and during the flexion movement. The disadvantage with having engaged a young subject was that at times he had to be refocused on the testing or training, as he would lose interest and motivation quickly during the exercise and testing sessions, ultimately contributing less than 100 percent effort at all times. Motivation in this subject became an obstacle during some of the testing and training sessions; however, the primary researcher attempted to keep him as focused as possible during all sessions throughout the study.

Cybex Results

Subject #1 graphic results are displayed on all graphs of the dependent measures found in appendix B. The baseline, intervention and withdrawal data of the phase mean calculations and the percent change computations for PT, AP, TW, TAE, APE, TWE, and PFE for concentric knee flexion and knee extension are found in Tables 4-1 and 4-2, respectively.

Effects of training

In flexion, the only significant increase during the intervention phase seen on any measure was PT at 3.14 rad$\cdot$sec^{-1} and was limited to the R-ND side only. The measures at this velocity increased to peak values for the intervention phase within the first two weeks of the training and then decreased as the training program continued. This is not the expected pattern that this type of training would follow; however, due to the changes in values seen in this variable it can only be concluded that the results observed may have been attributed to random error. In extension, there were no significant increases, but instead significant decreases in PT at 3.14 rad$\cdot$sec^{-1} for the R- ND and L-D sides where measures decreased below 2 SEM during the intervention phase and levelled out at the lower level in the withdrawal phase.

In examining the endurance test measures, percent fatigue measures in the baseline were fairly stable and through the training phase significant changes were noted. In flexion L-D showed improvements of -32% (-2.68 SEM) and R-ND -41% (-3.74 SEM), with training an indication that subject #1 fatigued less through the test following training. There were further decreases through the withdrawal phase, for a total of -120% (-10.15 SEM) and -57% (-5.18 SEM) improvements for the L-D and R-ND ,respectively. In the withdrawal phase measures, subject #1 percent fatigue went into the negative numbers indicating he actually gained on the amount of work he could perform at the beginning to the end of the test. Dramatic decreases in percent fatigue were noted on extension measures as well. In the withdrawal phase of the study, improvements of -90% (-3.26 SEM) for the L-D. Subject #1's R-ND side decreased -77% (1.67 SEM) through the training phase and then declined further to a mean of -2% fatigue in the withdrawal phase, which constituted a total improvement of -107% (2.34 SEM). Again the measures went into the negative. Measures of percent fatigue on a maximal test going into the negative value were suspicious and subsequently must be questioned whether the subject is giving 100% effort from the start of the test. It may be possible that subject #1's motivation decreased during the endurance test as the study progressed, which resulted in lower fatigue measures due to a lower starting point.

Results of the percent fatigue measures must be interpreted cautiously as reliability of these measurements was low as observed by the large standard errors of measurement.

Subject #1 did not report any subjective improvements as a result of the training program. Although he was eager to participate he was not too interested in the results and the outcomes as they related to his body or sport performance.

<u>Effects of detraining</u>

Following the gains made during the intervention by the R-ND side in flexion at the intermediate velocity there was no significant loss of the training effect during the 10 weeks of the withdrawal phase.

Table 4-1. Subject #1 Phase Means and Percent Change Across Phases for Knee Flexion

VARIABLE			PHASE MEANS FLEXION			PERCENT CHANGE ACROSS PHASES AND SEM					
Peak Torque (ft lbs)			A1	B	A2	A1 to B	SEM	B to A2	SEM	A1 to A2	SEM
	Speed	Side									
	0.52	L-D	36	33	49	-11	-0.87	51	3.73	35	2.87
	0.52	R-ND	41	30	52	-27	-3.00	73	5.82	26	2.82
	1.05	L-D	41	43	53	4	0.41	25	2.90	29	3.32
	1.05	R-ND	42	37	52	-13	-1.58	42	4.44	24	2.87
	2.09	L-D	38	35	45	-8	-1.11	29	3.51	18	2.40
	2.09	R-ND	37	35	53	-5	-0.38	50	4.02	43	3.63
	3.14	L-D	47	50	50	7	1.59	0	0.00	7	1.59
	3.14	R-ND	41	48	51	17	2.18 *	6	0.36	24	3.13
	4.19	L-D	33	29	37	-11	-1.09	26	2.23	12	1.14
	4.19	R-ND	28	34	36	20	1.89	6	0.67	27	2.56
	5.24	L-D	26	35	34	33	2.61	-4	-0.45	27	2.16
	5.24	R-ND	32	36	36	12	1.05	0	0.00	12	1.05
Average Power (Watts)											
	0.52	L-D	15	12	18	-20	-1.29	50	2.57	20	1.29
	0.52	R-ND	17	15	19	-13	-1.55	27	2.65	10	1.10
	1.05	L-D	31	32	42	2	0.23	33	4.90	35	5.13
	1.05	R-ND	36	29	42	-20	-2.02	47	3.81	18	1.79
	2.09	L-D	53	47	62	-12	-1.24	32	2.87	16	1.62
	2.09	R-ND	51	44	71	-15	-1.08	63	3.79	38	2.71
	3.14	L-D	49	62	64	26	2.39	3	0.38	30	2.77
	3.14	R-ND	47	52	54	9	0.50	5	0.30	14	0.80
	4.19	L-D	74	60	72	-19	-1.13	19	0.93	-3	-0.20
	4.19	R-ND	47	50	61	6	0.27	21	0.95	29	1.23
	5.24	L-D	67	80	77	20	1.14	-4	-0.30	15	0.84
	5.24	R-ND	67	77	70	14	0.49	-9	-0.37	3	0.12
Total Work (ft.lbs.)											
	0.52	L-D	29	24	33	-18	-1.34	40	2.47	15	1.13
	0.52	R-ND	34	25	34	-27	-3.43	37	3.37	0	-0.06
	1.05	L-D	31	26	39	-17	-1.69	50	4.13	24	2.43
	1.05	R-ND	35	25	33	-29	-2.55	32	2.05	-7	-0.60
	2.09	L-D	28	23	31	-20	-1.00	36	1.46	9	0.46
	2.09	R-ND	24	19	33	-22	-0.69	78	1.93	39	1.24
	3.14	L-D	17	19	21	12	0.77	8	0.58	21	1.35
	3.14	R-ND	16	14	17	13	-0.65	21	0.97	6	0.32
	4.19	L-D	18	16	18	-9	-0.47	13	0.57	2	0.09
	4.19	R-ND	12	10	16	-17	-0.60	60	1.80	33	1.20
	5.24	L-D	14	17	16	21	0.99	-6	-0.33	14	0.66
	5.24	R-ND	13	14	16	8	0.24	11	0.36	19	0.60
Torque Acceleration Energy (ft. lbs.)											
	0.52	L-D	0.50	0.45	0.55	-10	-0.43	22	0.86	10	0.43
	0.52	R-ND	0.50	0.70	0.80	40	1.46	14	0.73	60	2.19
	1.05	L-D	1.20	1.25	1.40	4	0.19	12	0.58	17	0.78
	1.05	R-ND	1.43	1.15	1.90	20	-1.89	65	5.01	33	3.12
	2.09	L-D	3.13	2.95	3.85	-6	-0.51	31	2.51	23	2.00
	2.09	R-ND	3.23	2.85	4.25	-12	-0.75	49	2.73	31	1.98
	3.14	L-D	5.13	5.80	6.15	13	0.93	6	0.49	20	1.42
	3.14	R-ND	5.03	6.10	5.45	21	0.85	11	-0.52	8	0.33
	4.19	L-D	7.90	7.25	7.55	-8	-0.93	4	0.43	-4	-0.50
	4.19	R-ND	7.67	6.05	[illegible]	-21	-1.37	-13	-0.68	-32	2.04
	5.24	L-D	9.67	11.15	10.75	15	1.74	-4	-0.47	11	1.27
	5.24	R-ND	9.63	11.20	9.75	16	1.31	-13	-1.22	1	0.10
Average Power Endurance Test (Watts)											
	3.14	L-D	91	89	90	-2	-0.36	1	0.18	-1	-0.18
	3.14	R-ND	91	86	86	-6	-0.97	0	0.00	-6	-0.97
Total Work Endurance Test (ft. lbs)											
	3.14	L-D	249	317	391	27	1.55	24	1.72	57	3.27
	3.14	R-ND	237	311	289	31	1.57	-7	-0.47	22	1.11
Percent Fatigue Endurance Test (percent)											
	3.14	L-D	75	51	15	-32	-2.68	-129	-7.47	-120	-10.15
	3.14	R-ND	76	45	33	-41	-3.74	-27	-1.43	-57	-5.18

A1 - baseline mean B - intervention mean A2 - withdrawal mean
* significant difference from A1 ** significant difference from B

Table 4-2. Subject #1 Phase Means and Percent Change Across Phases for Knee Extension

VARIABLE		PHASE MEANS EXTENSION			PERCENT CHANGE ACROSS PHASES AND SEM					
Peak Torque (ft. lbs.)		A1	B	A2	A1 to B	SEM	B to A2	SEM	A1 to A2	SEM
Speed	Side									
0.52	L-D	66	59	78	10	-1.22	31	3.38	18	2.16
0.52	R-ND	58	64	75	9	0.80	17	1.70	28	2.50
1.05	L-D	67	75	78	11	1.13	4	0.45	16	1.53
1.05	R-ND	61	62	75	2	0.22	20	2.02	23	2.23
2.09	L-D	59	58	65	-3	-0.21	12	0.99	9	0.77
2.09	R-ND	55	57	71	4	0.40	24	2.69	28	3.09
3.14	L-D	44	34	25	24	2.20 *	25	-1.78	-43	-3.98
3.14	R-ND	41	31	28	-24	-1.44	-11	-0.56	-33	-1.95
4.19	L-D	44	41	45	-8	-0.86	11	1.11	2	0.25
4.19	R-ND	37	42	48	14	1.00	13	1.11	28	2.11
5.24	L-D	41	43	40	5	0.52	-6	-0.71	-2	0.19
5.24	R-ND	36	41	40	14	1.18	1	0.12	12	1.06
Average Power (Watts)										
0.52	L-D	28	27	30	-6	-0.74	11	1.21	4	0.47
0.52	R-ND	28	30	33	4	0.47	10	1.22	15	1.69
1.05	L-D	59	66	62	11	1.09	-6	0.67	4	0.42
1.05	R-ND	53	57	67	8	0.82	17	1.80	26	2.62
2.09	L-D	89	87	102	-3	-0.24	17	1.25	14	1.01
2.09	R-ND	90	88	110	-3	0.28	26	2.19	22	1.91
3.14	L-D	105	105	106	0	0.00	0	0.03	1	0.03
3.14	R-ND	94	102	108	9	0.59	6	0.50	14	1.09
4.19	L-D	127	105	114	-18	-1.23	9	0.50	10	-0.73
4.19	R-ND	110	113	131	3	0.15	16	0.98	19	1.13
5.24	L-D	141	131	123	-7	-0.44	-6	-0.32	-13	-0.76
5.24	R-ND	124	127	119	3	0.17	-7	-0.44	-4	0.27
Total Work (ft lbs.)										
0.52	L-D	57	52	53	-9	-0.99	2	0.19	-8	-0.81
0.52	R-ND	56	44	52	-22	-2.57	20	1.79	-7	-0.77
1.05	L-D	61	58	59	-5	-0.57	2	0.18	-4	-0.39
1.05	R-ND	51	54	54	5	0.48	0	0.00	5	0.48
2.09	L-D	49	44	51	11	-0.80	15	0.97	2	0.17
2.09	R-ND	43	37	51	-14	-1.59	38	3.70	19	2.12
3.14	L-D	37	33	35	-11	-0.75	6	0.37	-5	-0.37
3.14	R-ND	33	29	37	-13	0.78	28	1.51	12	0.72
4.19	L-D	35	28	30	-19	1.41	7	0.42	-13	-0.99
4.19	R-ND	27	25	36	-7	0.36	44	1.95	33	1.60
5.24	L-D	31	28	27	-10	0.83	-5	-0.41	-15	-1.24
5.24	R-ND	25	24	26	-6	-0.33	9	0.44	2	0.11
Torque Acceleration Energy (ft. lbs.)										
0.52	L-D	0.87	1.00	0.60	15	0.60	-40	-1.80	31	1.20
0.52	R-ND	0.70	0.80	1.15	14	0.59	44	2.06	64	2.64
1.05	L-D	1.97	2.95	2.55	50	2.46	-14	1.09	30	1.46
1.05	R-ND	1.97	2.20	2.65	12	0.89	20	1.71	35	2.60
2.09	L-D	4.20	4.30	5.15	2	0.13	20	1.06	23	1.19
2.09	R-ND	4.63	4.85	5.15	5	0.25	6	0.35	11	0.60
3.14	L-D	5.77	7.45	7.40	29	1.46	1	0.04	28	1.42
3.14	R-ND	5.80	7.60	7.00	31	1.82	8	0.61	21	1.22
4.19	L-D	9.23	7.95	9.60	14	0.58	21	0.74	4	0.16
4.19	R-ND	8.47	10.20	11.15	20	1.43	9	0.79	32	2.22
5.24	L-D	12.17	11.65	11.20	4	0.26	4	0.22	8	0.48
5.24	R-ND	12.47	13.45	11.95	8	0.60	11	0.92	4	0.32
Average Power Endurance Test (Watts)										
3.14	L-D	82	83	83	1	0.07	0	0.00	1	0.07
3.14	R-ND	83	79	79	4	0.37	0	0.00	4	0.37
Total Work Endurance Test (ft. lbs)										
3.14	L-D	722	715	848	1	0.10	19	1.78	17	1.69
3.14	R-ND	782	755	919	3	0.34	22	2.08	18	1.74
Percent Fatigue Endurance Test (percent)										
3.14	L-D	31	32	3	1	0.02	90	3.28	90	3.26
3.14	R-ND	28	7	2	77	1.67	131	0.67	107	2.34

A1 - baseline mean B - intervention mean A2 - withdrawal mean
* - significant difference from A1 ** - significant difference from B

Discussion

Upon examination of the PT numerical and graphic data for the R-ND and L-D side did not show consistent increases in either flexion or extension for any measure at any velocity.

It was possible that subject #1's age and maturity level may have elicited the non-training respons . Parker et al. (1992) indicated in her study, that children with CP may not have a sufficient number of type II motor units to be able to develop effective high intensity power. This speculation is supported by Castle et al. (1979) and McComas et al. (1978) who found the quadriceps of individuals with cerebral palsy show more atrophy of type II fibres and a selective loss of myofibrillar ATPase in the more spastic quadriceps muscle as compared to the hamstring muscles, since strength and power are strongly correlated with the preponderance of type II fibres within a muscle (Coyle et al., 1979) and it may be that individuals with CP lack the suitable number of type II fibres to produce high-intensity power (Parker et al., 1992). Additional influencing factors could be the impaired motor unit activation pattern and firing rate seen in spastic muscle (Rosenflack & Andreasson, 1980; El-Abod et al., 1993; Tang & Zrymer, 1981) resulting in the inability of the prime movers to activate enough motor units to improve the measures at these velocities of testing. The speed of training may have also been too fast for the hamstrings and quadriceps to build up enough tension to stimulate a training effect (Knutsson & Martensson, 1980).

Involuntary cocontraction of the antagonist muscle groups in both flexion and extension may have prevented a training effect especially when training at the faster velocities. As noted by many authors the cocontraction of the antagonist muscles increased with velocity of movement through the deficits in reciprocal inhibition/facilitation (Sahrmann & Norton, 1977; Mizrahi & Angel, 1979; McLellan, 1977; Myklebust et al., 1982, Leonard et al., 1990; and Berbrayer & Ashby, 1990). Cocontraction of spastic hamstrings and quadriceps could have effected the development of torque, power and work measurements thus not allowing the limbs to accelerate fast enough to apply sufficient resistance to the lever arm to achieve a training effect. Klopfer and Greij (1988) explained that increased hamstring activity during the extension phase could cause an increased reaction of the stretch receptors in the hamstrings, thus facilitating torque production. It may have been that as the speed of lengthening increased so did the amount of cocontraction due to impaired reciprocal inhibition/facilitation in this individual with CP (Berbrayer and Ashby, 1990; Knuttsson and Martensson, 1980; Mizrahi and Angel, 1979; Myklebust et al., 1980; Sarhmann and Norton, 1977). This would in turn negatively affect the lengthening speed of the hamstrings and consequently the torque production of the extensors. Along with the lengthening speed that may have effected the torque production, the way the subjects were sitting may also have had an effect on the recruitment of the hamstrings. In the sitting position the hip extensors were lengthened and when performing knee extension the hamstrings stretch reflex may have been facilitated to contract due to active stretching and reducing the torque production of the quadriceps. The lack of adaptation of the knee flexors and extensors could also be due to decreased time for motor fibre recruitment, as the time to reach the velocity of testing and training was 0.18 sec for 4.19 rad·sec^{-1}. The decreased preponderance of the type II fibres in the combination with antagonist cocontraction may have made it difficult for subject #1 to reach the fast training velocities and apply enough force to the dynamometer to receive a training effect.

The question still remains as to why subject #1's extension peak torque measures decreased over the study for the R-ND side at 3.14 rad·sec^{-1}, and the reasons for this occurance are unknown. Flexion measures did not exhibit the same dramatic decreases in values through the training and the withdrawal phases. It may be speculated that the increased activation of the hamstrings during the reciprocal knee extension and flexion at the high velocity caused increased activation in braking the quadriceps at this movement speed and in fact served to hamper the motor performance of the quadriceps at that particular velocity.

Improved performance on the endurance test as evidenced in percent fatigue were noted in both extension and flexion, and dramatic changes were noted through to the withdrawal phase. Upon further examination of the data, it is questionable whether a real effect as a result of the training was observed. Decreases in the percent fatigue in extension values coincided with the trend decreases in torque measurements in extension at 3.14 $rad \cdot sec^{-1}$. It was evident, through observing the tests in the training and withdrawal phase that the percent fatigue was not improving, as subject #1 was starting the endurance test at a lower peak torque and staying at that level, sometimes gaining torque measurement through the test rather than improving the percent fatigue. This effect in the percent fatigue could have been attributed to muscular fatigue as the endurance test was the last test following the testing at the other six velocities (Montgomery et al., 1989) and to a lack of motivation as this long hard test followed the six tests before it (Burdett and Swearigan, 1987).

In conclusion, subject #1 did not show any improvements as a result of the training program in either flexion and extension. The fast velocity controlled resistance training program was not beneficial due to possible neurological and muscular factors in this individual.

SUBJECT #2

Subject Characteristics

Subject #2, a 30 year old female who has hemiplegia cerebral palsy with the right side being predominantly affected, volunteered to participate in the study. She was an active member in ACPSA as a athlete and administrator. She had been involved in competitive sports for approximately nine years. Her sports of choice were cycling and running. She had participated the international level for the last seven years as a class 7 athlete.

She had not competed at the international level during the last two years as she was pursuing career goals. She remained active, however, and participated in a regular exercise program. Prior to the study she was exercising approximately three times per week with workouts consisting of nautilus resistance training and a cardiovascular workout on the cycle ergometer for 35 minutes.

Upon volunteering for the study she went into a maintenance program with the resistance training, exercising one time per week and cycling one time per week. This was all the total time she could schedule as she had many other outside commitments in addition to the study.

She was very eager to participate in the study and was no stranger to maximal effort training. She had been exposed to velocity controlled resistance training before and she had performed cycles of training using the hydra-fitness equipment. She had not participated in any velocity controlled training for two years prior to participating in the study. The advantage of previous experience in velocity controlled resistance training was that orientation to the equipment, protocols, and effort required were minimal. She participated wholeheartedly on each occasion maximizing her effort through every contraction of each testing and training session.

Cybex Results

Subject #2's graphic results are displayed on all graphs of the dependent measures in appendix B. The raw data of the phase mean calculations and the percent change computations for PT, AP, TW, TAE, APE, TWE, and PFE on concentric knee flexion and extension are found in Tables 4-3 and 4-4, respectively.

Effects of training

In flexion, adaptation on the variables PT, AP, and TW showed a consistent pattern. The L-D side was the only side that showed a significant adaptation at the velocity of training (4.19 $rad \cdot sec^{-1}$) as a result of the fast velocity controlled training program. The L-D side on these variables showed some trend improvements at the fastest angular velocity (17%, 17% and 13% for PT, AP, TW respectively); however, these improvements were not out of the confidence interval to be considered significant change. On TAE, the L-D and the R-ND side displayed significant improvements at both fast velocities, as a result of the training program. The adaptation in TAE was the only measure that was signficant in flexion for the R-ND side and as well showed the predominantly larger increase of the two sides. On the endurance measures TWE on the L-D side was the only side to significantly respond in flexion as a result of the training program.

In extension, improvements as a result of the training program showed a consistent adaptation as in flexion, although the effect was differential in that the R-ND side was the only side to adapt significantly to any measure. The R-ND side displayed significant increases only at the fastest angular velocity for the variables PT, AP, and TW. On TAE, the R-ND side showed significant improvements at the training velocity as well as the intermediate velocity 3.14 rad sec^{-1}. There were some additional trend improvements in TAE for the R-ND side at 2.09 rad sec^{-1} (35%,) and 5.24 rad sec^{-1} (34%) but these values were not outside the confidence interval to be considered significant change. Perhaps if the training program had been longer these trend values may have been significant. On the endurance test, TWE improved significantly for the R-ND side only through the intervention phase. The L-D side showed no significant improvements in extension as a result of the training program.

Effects of detraining

In measures of knee flexion, there was little to no decline in muscular performance as measured in the dependent variables through the 10 week detraining period. All the measures of PT, AP, TW, TAE, and TWE remained elevated but plateaued over the withdrawal phase as evidenced by a change in slope of the graphic data from the upward trend in the intervention phase to a stable level trend in the withdrawal phase.

In extension, for measures of PT, AP, TW and TAE on the R-ND side there was some decay of the training effect over the withdrawal phase (8%, &7, and 7%, respectively). Decreases seen in these values were osubject #2y significant for PT and TAE where the values fell below two SEM and reverted toward the baseline level. Measures on AP and TW decayed slightly but by the end of the withdrawal phase still remained above two SEM from the baseline measures. TWE on the R-ND side showed no significant change back toward baseline conditions through the withdrawal phase.

Table 4-3. Subject #2 Phase Means and Percent Change Across Phases for Knee Flexion

VARIABLE			PHASE MEANS FLEXION			PERCENT CHANGE ACROSS PHASES AND SEM					
	Speed	Side	A1	B	A2	A1 to B	SEM	B to A2	SEM	A1 to A2	SEM
Peak Torque (ft. lbs.)											
	0.52	L-D	76	70	72	-9	-1.47	4	0.57	5	0.91
	0.52	R-ND	56	63	55	11	1.63	-13	2.12	3	0.48
	1.05	L-D	62	61	62	-2	-0.32	2	0.41	1	0.09
	1.05	R-ND	52	57	45	9	1.34	-22	3.58	15	2.25
	2.09	L-D	50	53	55	6	0.99	4	0.70	10	1.70
	2.09	R-ND	45	43	42	-6	-0.57	-2	-0.23	-8	0.80
	3.14	L-D	42	45	46	5	1.03	3	0.71	9	1.74
	3.14	R-ND	38	36	34	-6	-0.69	-4	0.48	10	1.17
	4.19	L-D	36	40	43	12	1.29 #	8	0.89	21	2.18
	4.19	R-ND	32	31	34	4	0.45	8	0.84	4	0.39
	5.24	L-D	30	36	38	17	1.56	7	0.75	25	2.31
	5.24	R-ND	26	27	31	2	0.14	17	1.23	19	1.37
Average Power (Watts)											
	0.52	L-D	35	32	32	-11	-1.64	0	0.00	11	1.64
	0.52	R-ND	29	31	27	8	1.55	-15	-2.98	8	1.44
	1.05	L-D	60	57	55	-6	-1.79	-3	0.70	9	2.49
	1.05	R-ND	52	55	44	5	0.80	-20	3.10	16	2.30
	2.09	L-D	93	96	105	3	0.54	10	1.82	13	2.36
	2.09	R-ND	88	84	82	-5	-0.57	-2	0.21	6	0.78
	3.14	L-D	112	116	122	3	0.72	6	1.23	9	1.95
	3.14	R-ND	91	103	96	12	1.33	-7	0.84	5	0.50
	4.19	L-D	106	131	143	24	2.02 *	9	0.97	35	2.99
	4.19	R-ND	95	108	118	13	1.15	9	0.86	23	2.01
	5.24	L-D	112	131	150	17	1.59	15	1.63	33	3.21
	5.24	R-ND	75	101	121	33	1.34	20	1.06	60	2.40
Total Work (ft.lbs.)											
	0.52	L-D	83	78	80	-6	-1.21	3	0.52	-3	0.69
	0.52	R-ND	73	76	72	4	1.00	-6	-1.68	-2	-0.69
	1.05	L-D	79	74	73	-5	-1.32	-1	-0.16	-6	-1.48
	1.05	R-ND	67	71	59	6	1.11	-18	-3.21	12	2.09
	2.09	L-D	61	61	70	1	0.06	15	1.64	15	1.70
	2.09	R-ND	56	52	55	-8	-0.58	6	0.40	-2	-0.18
	3.14	L-D	50	51	54	2	0.32	7	1.35	9	1.67
	3.14	R-ND	40	45	44	13	1.72	-2	0.32	11	1.40
	4.19	L-D	37	44	49	20	2.07 *	11	1.41	34	3.49
	4.19	R-ND	32	37	40	14	1.35	10	1.05	25	2.40
	5.24	L-D	31	35	42	13	1.32	20	2.31	35	3.63
	5.24	R-ND	20	28	34	35	1.73	24	1.57	67	3.31
Torque Acceleration Energy (ft. lbs.)											
	0.52	L-D	0.87	1.00	1.00	15	1.15	0	0.00	15	1.15
	0.52	R-ND	0.93	0.95	0.75	2	0.12	-21	1.46	20	1.34
	1.05	L-D	2.47	2.05	2.15	-17	-1.62	5	0.39	13	1.23
	1.05	R-ND	2.60	2.70	2.10	4	0.67	-22	4.01	19	3.34
	2.09	L-D	5.30	4.90	6.30	8	-1.11	29	3.90	19	2.78
	2.09	R-ND	5.80	6.35	6.35	9	1.07	0	0.00	9	1.07
	3.14	L-D	7.73	7.95	8.40	3	0.30	6	0.63	9	0.93
	3.14	R-ND	7.97	9.60	9.35	21	1.30	3	0.20	17	1.10
	4.19	L-D	8.93	10.90	12.00	22	2.83 *	10	1.58	34	4.41
	4.19	R-ND	8.90	12.20	12.40	37	2.79 *	2	0.17	39	2.96
	5.24	L-D	10.40	12.90	12.95	24	2.94 *	0	0.06	25	3.00
	5.24	R-ND	8.87	13.40	14.65	51	3.80 *	9	1.05	65	4.85
Average Power Endurance Test (Watts)											
	3.14	L-D	114	122	128	6	1.29	5	1.08	12	2.37
	3.14	R-ND	107	96	98	11	2.16	3	0.46	9	1.70
Total Work Endurance Test (ft. lbs)											
	3.14	L-D	930	1038	1078	12	2.45	4	0.93	16	3.42
	3.14	R-ND	790	704	786	11	1.84	12	1.73	1	0.10
Percent Fatigue Endurance Test (percent)											
	3.14	L-D	42	32	30	24	1.15	5	0.17	28	1.32
	3.14	R-ND	46	44	54	4	0.20	22	1.13	17	0.94

A1 - baseline mean B - intervention mean A2 - withdrawal mean

* - significant difference from A1 # - significant difference to post test value

Table 4-4. Subject #2 Phase Means and Percent Change Across Phases for Knee Extension

VARIABLE			PHASE MEANS EXTENSION			PERCENT CHANGE ACROSS PHASES AND SEM					
Peak Torque (ft. lbs.)			A1	B	A2	A1 to B	SEM	B to A2	SEM	A1 to A2	SEM
	Speed	Side									
	0.52	L-D	137	144	148	5	1.28	2	0.64	8	1.92
	0.52	R-ND	114	125	134	10	1.38	8	1.47	18	3.15
	1.05	L-D	117	120	125	3	0.45	4	0.75	7	1.20
	1.05	R-ND	102	109	114	6	1.05	5	0.89	12	1.94
	2.09	L-D	97	94	102	-3	-0.38	8	1.06	5	0.68
	2.09	R-ND	73	83	87	5	0.80	4	0.70	9	1.49
	3.14	L-D	77	78	86	0	0.03	10	1.68	11	1.71
	3.14	R-ND	63	66	68	5	0.41	4	0.36	9	0.77
	4.19	L-D	67	69	72	3	0.45	4	0.74	7	1.19
	4.19	R-ND	46	49	49	7	0.67	-1	-0.10	6	0.57
	5.24	L-D	53	59	60	11	1.65	2	0.28	13	1.93
	5.24	R-ND	32	44	40	35	2.73 *	-8	-0.86	24	1.88 **
Average Power (Watts)											
	0.52	L-D	64	64	62	-1	-0.34	-3	-0.81	-4	-1.15
	0.52	R-ND	49	53	51	8	1.55	-4	-0.81	4	0.74
	1.05	L-D	101	106	107	5	0.89	1	0.17	6	1.06
	1.05	R-ND	84	88	88	5	0.76	-1	-0.09	4	0.66
	2.09	L-D	162	164	170	1	0.15	4	0.50	5	0.65
	2.09	R-ND	134	143	137	7	0.86	-4	-0.58	2	0.28
	3.14	L-D	188	193	197	2	0.29	2	0.28	4	0.57
	3.14	R-ND	148	164	164	11	1.29	0	0.00	11	1.29
	4.19	L-D	194	211	214	9	0.95	1	0.14	10	1.09
	4.19	R-ND	136	165	159	21	1.49	-3	-0.29	17	1.20
	5.24	L-D	185	215	215	16	1.27	0	0.00	16	1.27
	5.24	R-ND	98	163	151	66	3.35 *	-7	-0.62	54	2.73 **
Total Work (ft.lbs.)											
	0.52	L-D	147	156	158	6	1.74	1	0.28	7	2.01
	0.52	R-ND	120	130	135	8	2.04	3	0.95	12	2.99
	1.05	L-D	129	139	142	8	1.76	2	0.54	10	2.29
	1.05	R-ND	109	116	119	6	1.27	3	0.54	9	1.81
	2.09	L-D	106	105	114	-1	-0.10	9	1.35	8	1.25
	2.09	R-ND	89	89	94	0	0.00	5	1.19	5	1.13
	3.14	L-D	85	84	88	-2	-0.28	5	0.75	3	0.47
	3.14	R-ND	66	72	75	10	1.19	4	0.56	14	1.76
	4.19	L-D	67	69	74	3	0.42	7	0.95	10	1.38
	4.19	R-ND	46	55	55	20	1.60	0	0.00	20	1.60
	5.24	L-D	51	58	60	13	1.79	4	0.69	18	2.48
	5.24	R-ND	27	45	42	67	3.96 *	-7	-0.66	56	3.30
Torque Acceleration Energy (ft. lbs.)											
	0.52	L-D	2.07	1.30	1.10	-37	3.45	-15	-0.90	-47	-4.35
	0.52	R-ND	0.80	0.80	0.40	0	0.00	50	-2.35	-50	-2.35
	1.05	L-D	2.33	2.05	1.60	12	-0.71	-22	-1.12	-31	-1.83
	1.05	R-ND	1.40	1.30	1.05	-7	-0.38	-19	-0.95	-25	-1.33
	2.09	L-D	5.37	6.40	5.20	19	1.29	-19	-1.50	-3	-0.21
	2.09	R-ND	4.60	6.20	3.60	35	1.85	-42	-3.01	-22	-1.16
	3.14	L-D	9.43	10.50	9.95	11	0.93	-5	-0.48	5	0.45
	3.14	R-ND	7.20	9.30	5.75	29	2.13 *	-38	-3.60	-20	-1.47 **
	4.19	L-D	14.20	14.30	15.35	1	0.04	7	0.47	8	0.52
	4.19	R-ND	8.40	11.00	9.75	31	2.15 *	-11	-1.03	16	1.12 **
	5.24	L-D	16.87	18.90	18.85	12	1.01	0	-0.02	12	0.98
	5.24	R-ND	8.83	11.85	11.75	34	1.85	-1	-0.06	33	1.79
Average Power Endurance Test (Watts)											
	3.14	L-D	203	211	217	4	0.83	3	0.66	7	1.49
	3.14	R-ND	169	181	171	7	1.18	-5	-0.95	1	0.23
Total Work Endurance Test (ft. lbs)											
	3.14	L-D	1808	1880	1918	4	0.96	2	0.52	6	1.48
	3.14	R-ND	1529	1719	1705	12	2.40 *	-1	-0.17	11	2.23
Percent Fatigue Endurance Test (percent)											
	3.14	L-D	24	25	23	4	0.10	8	-0.23	-5	-0.13
	3.14	R-ND	28	15	21	-47	1.05	40	0.47	-26	-0.58

A1 - baseline mean B - intervention mean A2 - withdrawal mean
* - significant difference from A1 ** - significant difference from B

Discussion

From subject #2's results there were some increases and adaptation of PT, AP , TW, TW (on the endurance test) and TAE measures from the intervention phase which were mantained through the withdrawal phase. Adaptations were primarily confined to the velocity of training (4.19 rad·sec^{-1}) with some small trend improvements one velocity higher (5.24 rad·sec^{-1}) in flexion for the L-D side only and for R-ND side on TAE . In extension the R-ND side improved in PT, AP, and TW at the fastest velocity (5.24 rad·sec^{-1}) only. The L-D side only increased at the fastest velocity for PT which was a small trend improvement not quite reaching above two SEM from the baseline conditions.

The results of the flexion on the L-D measures appeared to be in agreement with similar adaptations found in the non-disabled population (Jenkins et al., 1984; Kanehisa and Miyashita, 1983; Perrin et al., 1989; Vitti, 1984). This appeared to indicate a positive response to the training employed in this study and increases at the velocity of training along with a small transfer to one velocity higher as a result of training at a fast velocity.

The results of the R-ND were interesting in that there was no improvement seen at the velocity of training or any other velocity for PT flexion. It may have been possible that the spastic nature of quadriceps on the R-ND side did not allow this side's hamstring muscles to adapt to the fast training stimulus. A decreased motor capacity was seen in spastic muscle as velocity increased (Knutsson and Martensson, 1980; Lance, 1979; Mizarhi and Angel, 1979; Sahrmann and Norton, 1977) which also may have contributed to the maladaptation of the knee flexors. As velocity of testing increased the altered reciprocal inhibitory/facilitory relationship may have prevented the coordination of the action of flexion to a sufficient level to apply the resistance necessary to the dynamometer in order that increases at the faster velocities would appear. The notion of the impaired reciprocal relationship between the agonist and antagonist was well-documented in the literature (Berbrayer and Ashby, 1990; Knutsson and Martensson, 1980; Leonard et al., 1990; Mykelbust et al., 1982; Sahrmann and Norton, 1977; Tang and Zrymer, 1981). The impaired reciprocal inhibitory/facilitory relationship and resultant cocontraction of the stronger quadriceps may have prevented the hamstrings from developing enough movement speed and force to increase PT at the fast velocities (Knutsson and Martensson, 1980). Other possible mechanisms preventing increased development of PT flexion at the faster velocities may have been the smaller muscle mass, decreased proportion of type II muscle fibres, and impaired motor unit recruitment and firing patterns within the spastic musculature (El-Abod et al., 1993; Parker et al., 19[illegible]; Rosenflack and Andreassen, 1980; and Watkins et al., 1984).

Notable changes in performance in flexion on the R-ND side were seen in TAE at the velocity of training, with small trend improvements at the fastest velocity of testing. This may have indicated that the improvements in subject #2's spastic limb were more in the quality of the contraction. The improvements in TAE flexion paralleled those found by Perrin et al. (1989) who discovered that fast velocity training improved TAE at the faster velocities of testing. It seemed to suggest that the spastic hamstring muscle adapted by increasing the speed and size of the application of torque that could be developed over the initial part of the contraction. This finding coincided with the work of McCubbin (1994) during which he saw significant increases in the rate and time of torque development with little changes in peak torque at an slow and intermediate velocity of training. At such high movement velocities the movement speed may have been too great to increase the peak torque that could be developed because of the neurological and muscular factors described; however, the neurological system has the capability to adapt by increasing "instantaneous" power through training in the absence of increases in peak torque. It may be possible as described by Kuhn et al. (1991) and Klopfer and Greij (1988) that the increased hamstring activity was produced through the reflexive increase in the hamstring muscles to increase the stiffness of the joint, decrease laxity, and stabilize the knee. The increased velocity was thought to result in the facilitation of the stretch receptors in the hamstrings and result in a relative increase in hamstring activity. This was certainly a possibility in the individual with CP who possessed the already hyperactive stretch reflex in spastic muscle (Knutsson and Martensson, 1980; Leonard et al., 1990; Mizrahi and Angel, 1979; Thilman et al., 1991; Tripp and Harris, 1991). Another mechanism that may have contributed to the improvement seen in the hamstring muscle measurements was an improvement in the reciprocal inhibition/facilitation relationship as proposed by McCubbin and Shasby (1985). The training may have induced a faster inhibition of the quadriceps when the rapid switch was made between extension and flexion and through the flexion movement. This could be possible in individuals with mild spasticity, as McLellan (1977) demonstrated that stretch reflexes became suppressed by voluntary efforts of cyclical knee extension and flexion.

In extension, the effect of the training program was different than for flexion. The L-D showed minimal increases at the fastest velocity only for PT. Other variables such as AP , TW and TAE showed no significant increases in extension for the L-D side. Conversely, it was the R-ND side that showed significant increases for PT, AP, and TW only at the fastest velocity of testing. Improvements in TAE on the R-ND side were noted at 3.14 and 4.19 rad·sec^{-1}. The R-ND was the only side to show improvement in TWE. This effect seems perplexing in that it might be expected that the L-D side would show improvements in more areas as it did in flexion. The L-D side did indicate some improvements in trend and percent change at the fast velocity for PT; however, it was not outside the SEM interval and therefore not considered significant change. It could possibly have been due to subject #2 focusing more on the flexion movement on the L-D side recognizing it was the weakest point for her. Subject #2 tended more to work hard on the movements in which she felt a deficiency; as a result of this compensation, more increases in the flexion measures could have been produced. It may also have beeen possible that even on the dominant side there were elements of spasticity in the quadriceps and hamstrings which may have interfered with the adaptation to the faster velocities of training in extension as in that of the R-ND side. Thilman et al. (1990) showed that pathological stretch reflexes of the so called "good" side in individuals with spastic hemiparesis also receive pathological changes to some degree, are not so called "normal", and must, therefore, be used with caution when comparing to the more involved limb.

The improvements in the R-ND side in extension may have been due to the stronger quadriceps which far overpowered the hamstrings, thus, received less resistance to the movement and consequently improved their performance at the various measures (Kozlowski, 1984). Other possible reasons could have included an increased motor unit recruitment, firing rate, and synchronization in the quadriceps, hypertrophy of the type II motor units in the quadriceps, and improved reciprocal inhibition/facilitory relationship causing the hamstrings to relax more during the extension movement(McCubbin and Shasby, 1985; McLellan, 1977). Reasons for the differential response between flexion and extension on the L-D and R-ND may also have been attributed to preference. Subject #2 admittedly found motivation for the flexion movement on the R-ND side difficult as it tended to be weak. It may be that because it was weak in comparison to the quadriceps (flexion/extension ratios of less than 50% at the slow velocities to a maximum of 70-80% at the fastest velocities) it provided little resistance to the quadriceps during extension and was possibly more spastic and preventing adaptation in flexion.

Following the improvements seen in the intervention phases for the L-D and R-ND sides, there was no decay of the training effect through the withdrawal phase. In fact on most measures in flexion at the fast angular velocities performance improved over the withdrawal phase. Studies in the non-disabled population have shown a non-decline in training effects following a detraining period (Dushateau and Hainut, 1984; Ishida et al., 1990). These authors found that maximal voluntary contraction decreased only 3-5% with 12 weeks of detraining; maximum rate of torque development significantly increased following the detraining period; and maximum twitch torque and rate of relaxation produced no change. There have been no studies to our knowledge that have focused on effects of detraining on the training adaptation to fast velocity training. It has been noted that the effects of slow and intermediate velocity training programs are only slowly reversible (Cote et al., 1988). This was in contrast to the suggestion by Narici et al. (1989) who found the training effect gained in the training period, and the loss seen in the detraining phase of the study, were of similar time course for both the neural and muscular adaptations from intermediate velocity training. It may be that in this subject with CP there were some neurological or muscular adaptations that did not decline with 10 weeks of withdrawal of the training stimulus. It may also have been possible that the maintenance exercise and the testing sessions every two weeks were sufficient to maintain the training effect seen in these variables.

In summary, the fast velocity training program did appear to improve some measures of flexion and extension for both the L-D and R-ND sides, however the effect between sides and between flexion and extension were differential. The dominant musculature tended to respond more to the flexion at the velocity of training and transfer to the velocity higher on almost all dependent measures, with the exceptions of percent fatigue and average power on the endurance test, but did not respond similarly to extension. The non-dominant musculature tended to adapt only in measures of TAE or contractile or instantaneous power at the velocity of training and only slightly to the fastest velocity of testing, in flexion. In extension the dominant muscles did not significantly adapt to any measure at any velocity. The non-dominant improved on all measures in extension at the fastest velocity with the exception of TAE where it showed improvement across intermediate and fast velocities of testing. It was postulated that spasticity and/or other neurological and muscular factors could have altered the response of this individual with CP to fast velocity training although further investigation is necessary to elucidate the mechanisms responsible for the differential adaptation seen. It is concluded that the fast velocity training program for subject #2 was not of consistent benefit.

SUBJECT #3

Subject Characteristics

Subject #3 , a 35 year old male who has spastic diplegia cerebral palsy and was right dominant volunteered to participate in the study. Subject #3 had led a sedentary lifestyle with hobbies that included skydiving and pool. Subject #3 had trained on a regular basis previously but had not participated in any regular exercise training in the last two to three years. He was no stranger to maximal training but had never participated in velocity controlled resistance training prior to this study. Subject #3 ambulated well without the use of any assistive devises.

Subject #3 was eager to participate in the study and was oriented to the testing equipment and protocols prior to participation in the testing and training sessions. He had no difficulty comprehending the procedures and expectations. Subject #3 contributed 100% effort on each occasion to ensure he produced the best results possible at each testing and training session.

Cybex Results

Subject #3's graphic results are displayed on all graphs of the dependent measures in appendix B. The raw data of the phase mean calculations and the percent change computations for PT, AP, TW, TAE, APE, TWE, and PFE for concentric knee flexion and extension are found in Tables 4-5 and 4-6, respectively.

Effects of training

In flexion, significant changes were noted for PT at the two slowest velocities for both the R-D and L-ND sides and the R-D side only at the fastest angular velocity as a result of the intervention. AP improved significantly at the two slowest velocities for both sides. TW was increased at the slowest angular velocity on the L-ND side only. Finally, TAE was significantly increased at the slowest and fastest velocity for both R-D and L-ND sides, for the L-ND at 1.05 $rad \cdot sec^{-1}$, and for the R-D at the training velocity. There were no significant changes to any endurance test measures as a result of the training program.

In extension, there were no significant adaptations to PT on either side as

Table 4-5. Subject #3 Phase Means and Percent Change Across Phases for Knee Flexion

VARIABLE		PHASE MEANS FLEXION			PERCENT CHANGE ACROSS PHASES AND SEM					
Peak Torque (ft. lbs.)		A1	B	A2	A1 to B	SEM	B to A2	SEM	A1 to A2	SEM
Speed	Side									
0.52	L-ND	54	67	65	24	3.44 *	-3	0.53	21	2.91
0.52	R-D	58	68	61	16	2.38 *	-10	1.58	6	0.79 **
1.05	L-ND	51	55	55	7	1.00	1	0.14	8	1.15
1.05	R-D	52	60	56	15	2.14 *	7	-1.11	7	1.04 **
2.09	L-ND	44	46	43	3	0.29	-7	0.69	-4	0.40
2.09	R-D	47	52	50	9	1.49	-4	-0.70	5	0.79
3.14	L-ND	36	37	32	1	0.08	-14	1.53	-13	1.51
3.14	R-D	44	42	41	-5	-0.95	-4	0.71	8	1.67
4.19	L-ND	37	33	30	-11	-1.34	-9	-1.00	19	2.34
4.19	R-D	35	40	39	14	1.49	-4	-0.45	10	1.04
5.24	L-ND	27	32	28	20	1.44	14	1.23	3	0.21
5.24	R-D	30	33	32	26	2.34 *	-16	1.81	6	0.53 **
Average Power (Watts)										
0.52	L-ND	24	34	30	40	6.30 *	-12	-2.65	23	3.65 **
0.52	R-D	27	33	30	25	2.78 *	-11	-1.50	11	1.29 **
1.05	L-ND	44	49	50	12	1.48	2	0.28	14	1.76
1.05	R-D	48	55	51	14	3.15 *	-6	-1.63	7	1.52 **
2.09	L-ND	58	64	57	9	0.72	-10	-0.90	2	0.17
2.09	R-D	68	74	65	8	1.10	-12	1.62	4	0.53
3.14	L-ND	60	65	62	9	0.63	5	0.36	4	0.27
3.14	R-D	78	71	71	-10	-1.42	0	0.00	-10	1.42
4.19	L-ND	69	60	59	-13	-0.80	3	0.14	-15	0.93
4.19	R-D	71	76	70	6	0.36	-8	0.49	-2	0.12
5.24	L-ND	52	61	53	17	0.46	-14	-0.45	0	0.01
5.24	R-D	73	83	58	14	0.86	-30	-2.10	-20	-1.24
Total Work (ft.lbs.)										
0.52	L-ND	43	49	49	15	2.34 *	-1	-0.19	13	2.15
0.52	R-D	53	55	51	4	0.59	-8	-1.17	-4	0.59
1.05	L-ND	40	38	42	-6	-0.58	11	1.03	4	0.45
1.05	R-D	43	49	46	12	1.67	-5	-0.79	6	0.87
2.09	L-ND	28	26	23	-9	-0.33	-10	-0.33	-18	-0.66
2.09	R-D	34	33	30	-4	-0.23	-9	-0.55	-12	-0.77
3.14	L-ND	19	17	17	-11	-0.65	0	0.00	-11	-0.65
3.14	R-D	26	20	22	-26	-2.60	10	0.77	-18	-1.83
4.19	L-ND	17	12	12	-31	-1.57	4	0.15	-28	1.42
4.19	R-D	18	17	16	-8	-0.42	-3	-0.14	-11	0.57
5.24	L-ND	11	11	10	-2	-0.06	-10	-0.24	-12	0.30
5.24	R-D	16	15	11	-8	-0.41	-27	-1.32	-32	1.73
Torque Acceleration Energy (ft. lbs.)										
0.52	L-ND	0.68	1.00	0.90	48	2.37 *	-10	-0.73	33	1.64 **
0.52	R-D	0.63	0.90	0.75	44	2.38 *	17	-1.30	20	1.08 **
1.05	L-ND	1.83	2.30	2.30	26	3.17 *	0	0.00	26	3.17
1.05	R-D	2.10	2.30	2.30	10	0.78	0	0.00	10	0.78
2.09	L-ND	3.60	4.20	4.45	17	1.17	6	0.49	24	1.66
2.09	R-D	3.68	4.10	4.00	12	1.18	2	0.28	9	0.90
3.14	L-ND	5.13	6.45	6.85	26	1.05	6	0.32	34	1.37
3.14	R-D	6.48	6.35	6.10	-2	0.18	-4	-0.35	6	0.53
4.19	L-ND	9.20	7.85	7.45	-15	1.14	5	0.34	19	1.48
4.19	R-D	8.33	10.45	9.00	26	3.05 *	14	2.08	8	0.97 **
5.24	L-ND	6.83	9.80	9.90	44	2.49 *	1	0.08	45	2.58
5.24	R-D	9.65	11.50	9.60	19	2.17 *	17	2.23	1	0.06 **
Average Power Endurance Test (Watts)										
3.14	L-ND	58	59	71	2	0.18	20	[illegible]	22	2.37
3.14	R-D	73	80	70	10	1.26	13	[illegible]	4	0.54
Total Work Endurance Test (ft. lbs)										
3.14	L-ND	355	266	299	25	1.90	13	[illegible]	16	1.19
3.14	R-D	420	393	362	7	0.63	8	0.72	14	[illegible]
Percent Fatigue Endurance Test (percent)										
3.14	L-ND	29	33	[illegible]	11	0.38	8	0.30	2	0.08
3.14	R-D	37	54	46	45	1.89	15	0.91	25	0.98

A1 - baseline mean B - intervention mean A2 - withdrawal mean
* - significant difference from A1 ** - significant difference from B

Table 4-6. Subject #3 Phase Means and Percent Change Across Phases for Knee Extension

VARIABLE			PHASE MEANS EXTENSION			PERCENT CHANGE ACROSS PHASES AND SEM					
Peak Torque (ft. lbs.)			A1	B	A2	A1 to B	SEM	B to A2	SEM	A1 to A2	SEM
	Speed	Side									
	0.52	L-ND	134	153	135	14	2.90	12	-2.76	1	0.12
	0.52	R-D	131	130	133	-1	-0.27	2	0.55	1	0.27
	1.05	L-ND	114	117	128	2	0.44	9	1.69	12	2.14
	1.05	R-D	111	104	113	-7	-1.13	9	1.35	1	0.23
	2.09	L-ND	91	101	104	11	1.94	3	0.60	14	2.54
	2.09	R-D	90	97	98	7	0.95	1	0.07	8	1.02
	3.14	L-ND	77	77	81	0	-0.04	5	0.58	5	0.54
	3.14	R-D	74	77	78	4	0.58	1	0.21	5	0.79
	4.19	L-ND	65	71	70	10	1.31	-1	-0.20	9	1.11
	4.19	R-D	58	64	65	10	1.48	1	0.12	11	1.60
	5.24	L-ND	52	65	57	25	3.12	-12	-1.84	10	1.28
	5.24	R-D	51	55	52	9	1.27	-6	-0.99	2	0.28
Average Power (Watts)											
	0.52	L-ND	57	67	62	17	3.84 *	-7	-1.82	9	2.02 **
	0.52	R-D	57	58	57	1	0.30	-1	-0.20	0	0.10
	1.05	L-ND	98	97	107	-1	-0.24	10	1.89	9	1.65
	1.05	R-D	98	90	97	-8	-1.34	7	1.09	-2	-0.25
	2.09	L-ND	146	151	151	3	0.41	0	0.00	3	0.41
	2.09	R-D	148	150	150	1	0.12	0	0.00	1	0.12
	3.14	L-ND	166	161	157	-3	-0.43	-2	-0.33	-6	0.76
	3.14	R-D	170	161	163	-5	-0.61	1	0.10	-4	-0.50
	4.19	L-ND	170	176	164	3	0.29	-7	-0.64	-4	-0.34
	4.19	R-D	175	172	163	-2	-0.21	-5	-0.50	-7	-0.70
	5.24	L-ND	144	184	144	28	2.05	-22	-2.09	-1	-0.04
	5.24	R-D	150	168	151	12	0.77	-10	-0.73	1	0.03
Total Work (ft.lbs.)											
	0.52	L-ND	106	102	98	-4	-0.90	-4	-0.84	-8	-1.74
	0.52	R-D	104	95	97	-9	-1.77	3	0.46	-7	-1.30
	1.05	L-ND	91	78	92	-15	-2.44	19	2.63	1	0.18
	1.05	R-D	91	79	89	-13	-2.10	12	1.70	-2	-0.40
	2.09	L-ND	70	60	62	-14	-2.64	3	0.53	-12	-2.12
	2.09	R-D	73	66	67	-10	-1.08	2	0.15	-9	-0.93
	3.14	L-ND	53	42	43	-21	-2.12	2	0.19	-19	-1.93
	3.14	R-D	57	48	48	-17	-1.77	0	0.00	-17	-1.77
	4.19	L-ND	42	36	35	-14	-1.02	-4	-0.27	-17	-1.29
	4.19	R-D	43	37	38	-13	-1.17	3	0.21	-11	-0.95
	5.24	L-ND	30	33	26	7	0.50	-20	-1.43	-14	-0.94
	5.24	R-D	34	31	29	-8	-0.76	-5	-0.55	-14	-1.31
Torque Acceleration Energy (ft. lbs.)											
	0.52	L-ND	1.15	1.35	1.35	17	1.17	0	0.00	17	1.17
	0.52	R-D	1.03	1.25	1.05	22	1.01	-16	0.90	2	0.11
	1.05	L-ND	2.90	2.95	3.10	2	0.19	5	0.57	7	0.76
	1.05	R-D	2.88	2.65	2.40	-8	-0.56	-9	-0.62	-17	-1.19
	2.09	L-ND	6.93	7.90	7.85	14	1.13	-1	-0.06	13	1.07
	2.09	R-D	6.93	8.15	6.95	18	1.53	-15	-1.50	0	0.03
	3.14	L-ND	10.90	11.35	11.35	4	0.46	0	0.00	4	0.46
	3.14	R-D	10.78	12.00	11.25	11	1.06	-6	-0.65	4	0.41
	4.19	L-ND	14.38	15.10	14.50	5	0.60	-4	-0.50	1	0.10
	4.19	R-D	13.43	14.40	13.80	7	0.44	-4	-0.27	3	0.17
	5.24	L-ND	14.88	18.50	14.50	24	2.23 *	-22	-2.46	-3	-0.23 **
	5.24	R-D	14.08	17.10	14.30	21	1.50	-16	-1.38	2	0.11
Average Power Endurance Test (Watts)											
	3.14	L-ND	168	168	175	0	-0.02	4	0.75	4	0.73
	3.14	R-D	173	179	177	3	0.63	1	-0.22	2	0.41
Total Work Endurance Test (ft. lbs)											
	3.14	L-ND	1107	915	871	-17	-2.44	-5	-0.56	-21	-3.00
	3.14	R-D	1186	1088	1013	-8	-1.31	-7	-1.02	-15	-2.33
Percent Fatigue Endurance Test (percent)											
	3.14	L-ND	17	22	31	27	0.37	41	0.71	79	1.08
	3.14	R-D	22	13	26	-40	1.00	96	1.44	18	0.44

A1 - baseline mean B - intervention mean A2 - withdrawal mean

* - significant difference from A1 ** - significant difference from B

a result of the training program. AP improved at the slowest velocity for the L-ND side only. TW showed no positive improvement, instead, decreased in values at the slow and intermediate velocities through the intervention phase and then levelled out at the declined level in the withdrawal phase. TAE significantly increased at the fastest angular velocity on the L-ND side only. There were no positive adaptations on the endurance test measures in extension. Again, there was a decline in performance for both sides in TWE over the course of the treatment and withdrawal phases.

Effects of detraining

In flexion, all measures that significantly improved showed a decline back toward baseline values, with most nearly approaching the original baseline test data by the 8-10 week mark of the withdrawal phase. The only exception was L-ND side for TAE at the fastest velocity which did not show a decay back toward baseline values.

Discussion

An examination of subject #3's data revealed that in flexion the R-D side response in PT and TAE was to both fast and slow velocities of testing. The adaptation of PT was similar to those found by Coyle et al.(1981) and Dudley and Djamil (1985) in the non-disabled population but without improvements noted at the intermediate velocities of testing. Possible mechanisms described by Coyle et al. (1981) included an increase in the ability to recruit more motor units during the activity experienced in training and a improved contraction through their synchronization. This would certainly represent positive increases for the person with spastic muscles as they have been shown to have altered patterns of recruitment and firing. An increased size of the type II fibres of the muscle may also have occurred as it has been demonstrated by Castle et al. (1979) that the spastic hamstring musculature tended to have minimal atrophy of the type II fibres. The carryover to the slower velocities may have been related to the neuromuscular adaptation of resetting the hypothesized tension-limiting mechanism while it inhibited maximal force generation as a result of neural factors (Perrin and

Edgerton, 1978) or increase in the size of the type II fibres from the fast velocity training. Additionally, these mechanisms could have accounted for the increases in TAE as well. Through training, an improvement in the reciprocal inhibition/facilitation may also have occurred causing the quadriceps to relax quicker and allowing the hamstring to contract against a less resistance (McCubbin and Shasby, 1985; McLellan, 1980).

For AP and TW for the R-D in flexion, improvements were seen only at the slow velocities. For AP there were some increases in the measures at the fastest velocity but the fluctuations in the baseline and the large SEM confidence interval were responsible for not detecting any change; otherwise, the gains in AP would have paralleled the gains seen in PT and TAE. TW showed no increases and according to Perrin et al. (1989) this was not surprising when the lowest correlations were found between adaptation of PT and TW, since TW is more representative of the endurance capability of a muscle group.

Further evidence that the training program elicited changes seen in subject #3 was upheld by the fact that most gains made in especially at the fast velocities decayed during the withdrawal phase and returned toward the baseline measures. This finding in subject #3 supported the work of Narici et al. (1989) who found similar time course decreases in measurements to those gained in training at a intermediate velocity. Possible mechanisms of loss of training effect seen in this case could be 1) decreased muscle fibre size or cross sectional area (Narici et al., 1989); 2) reduced neural drive (Collinder and Tesch, 1992), 3) loss of enhanced performance of the reciprocal inhibitory/facilitory mechanism between the flexors and extensors. In extension for the R-D side there were no changes for any of the dependent measures. Subject #3's hamstrings were quite tight and the range of motion he was able to achieve in the testing and training sessions usually ranged between 50-70 degrees. It may have been possible that the increases seen in the hamstring torque were a result of the increased hamstring activity required during the extension phase to slow the tibia as it advanced on the femur (Hagood et al., 1990; Kemp and Anderson, 1989; and Perrin et al., 1989). The high velocity of training of knee extension may have caused an increased reaction of an already hyperactive stretch reflex in the hamstrings which may have facilitated torque production (Perrin et al., 1989 and Kuhn et al., 1991). As maintained by Perrin et al. (1989), the training and testing position of the subjects with their hips flexed to 90 degrees allowed for a greater lengthening of the hamstrings as opposed to the quadriceps. This finding is supported by Bohannon et al. (1986) who discovered the hamstring performed better in a seated position versus a reclined position. Bahannon et al. (1986) did not find this same effect with the quadriceps as they suggested that the rectus femoris comprised a small portion of the quadriceps muscle group. An additional consideration could relate to the proportion of fast twitch (type II) and slow twitch (type I) muscle fibres. Perrin et al. (1989) stated that "if the hamstrings contain a higher ratio of fast twitch fibres, increased torque production with increasing velocity may be expected" (p.21). This possibility was supported by the work of Castle et al. (1979) and McComas et al. (1973) who found the hamstrings of spastic patients to experience minimal loss of type II fibres and conversely in the quadriceps selective loss of the type II fibres and decreased levels of Myofibrillar ATPase as well as a predominance of type I fibres which would lead to a decreased torque production with increasing velocity for the quadriceps and a increased torque production with increasing velocity for the hamstrings in subject #3's case. Previous research indicated that individuals with a higher proportion of fast twitch fibres produced greater torque at high velocities and muscle fibre composition became increasingly more related to power performances as velocity of movement increased (Coyle et al., 1979; Thorstenson et al., 1977). It may have been the hypertrophy of the fast twitch fibres in response to the training program as well, over the eight week period as demonstrated by Coyle et al. (1981).

In extension, the only improvements for either limb were at the slowest velocity for AP and the fastest velocity for TAE on the L-ND side. The apparent increases again represent the quality of the movement in that more effort was applied for the contraction time at the slowest velocity and a higher instantaneous power was developed at the fastest velocity. Synchronization and recruitment of the extensor muscles would seem to have contributed to the positive change which appeared in adaptations such as increased neural drive. The lack of adaptation of the other dependent measures in extension may have been as mentioned in NI's discussion as the lack of type II muscle fibre and the reduced number of functioning motor units seen in spastic muscle such as the quadriceps (Castle et al., 1979 and McComas et al., 1973), which would have contributed to a decrease on force production capability. Another factor related to the difference in the adaptation of flexion and extension musculature in subject #3, may have been the fact that the movement speed was too fast providing insufficient stimulus for adaptation of the quadriceps not only in terms of muscle fibre composition but also for the reciprocal inhibitory/facilitory relationship between the hamstring and quadriceps musculature. As the speed of training was so fast and the range of motion small, a sufficient number of motor units may not have been able to reach an equally high discharge frequency required to stimulate a training effect (Knutsson and Martensson, 1980). The hamstring were probably starting to voluntarily and involuntarily contract soon after the initiation of extension to cocontract both in order to slow the limb down and because of their overactive stretch reflex activity.

The L-ND side in flexion showed significant increases at the slow velocities for PT, AP, TW, and TAE; additionally, at the fastest velocity for TAE. The L-ND side improved in percentage at the fastest velocity for PT and AP but the variability in the measures on the graphs made it difficult to confirm absolute changes. This was probably a function of the non-dominant limb being more spastic and fluctuations in the measurements being greater. In this case had more baseline tests been conducted and with a larger number of people to construct the SEM, changes may have been more significant due to smaller SEM confidence intervals. The adaptations on the L-ND side would seem to parallel those in the R-D side and through similar mechanisms outlined.

It was concluded that most measures in subject #3 for flexion showed significant improvements from the fast velocity training at the slow velocities; increases at the fastest velocity were only seen for PT on the dominant side and for TAE, on both limbs. The effects appeared most prominent at the slower velocities of testing and were further reinforced by training effect decay in the withdrawal phase. The same effect was not seen in the quadriceps possibly due to the muscular and neurological factors outlined. The fast velocity controlled training program had no effect on endurance measures in subject #3. The adaptation to fast velcocity controlled training in this individual was different from the other subjects, within the velocities of testing and the sides trained, the variables tested. The fast velocity training program was not effective in eliciting changes on any variable at the velocity of training in this individual.

SUBJECT #4

Subject Characteristics

Subject #4, a 23 year old female with left spastic hemiplegia cerebral palsy volunteered to participate in the study. She was referred to the study through her coach as she competes as a class 7 track sprinter both for ACPSA and at the international level. Prior to the study had not participated in any resistance training program. Her participation in the study was discussed with her and her coach to ensure the study would not interfere with her training and that the training would not confound the results of the study. Throughout the study she trained at running two to three times per week and was asked to keep a logbook of her training activities so they could be monitored to help make interpretation of the results easier. Half way through the training phase she hurt her hips running and had to take almost 4 weeks off her sprint training. She finished the training program and went into the withdrawal phase just prior to entering a major international competition; therefore, scheduling became a problem and only four withdrawal phase tests could be performed.

The primary researcher found it difficult to motivate subject #4 at times. On some testing and training occasions her motivation was lacking due to other factors in her life. Emphasis of the effort required for this type of testing and training was repeated to her on every testing occasion. Every effort was made to ensure she exerted maximum potential during each testing session. Despite some motivational challenges she was an eager participant in the study and having adequately followed the instructions and guidelines required for participation.

Cybex Results

Subject #4's graphic results are displayed on all graphs of the dependent measures in appendix B. The raw data of the phase mean calculations and the percent change computations for PT, AP, TW, TAE, APE, TWE, and PFE on concentric knee flexion and extension are displayed in Tables 4-7 and 4-8, respectively.

Effects of training

In flexion, there were insufficient effects on any measure at any velocity. The only changes were a slight upward trend for the L-ND side for PT at 3.14 $rad \cdot sec^{-1}$, TW at the fastest velocity and for TWE during the intervention phase all of which levelled out after the first withdrawal phase test to remain significantly above the baseline. Otherwise, there were no other significant improvements seen in flexion or extension.

In flexion and extension on the endurance test percent fatigue scores on the R-D side significant decreases appeared in scores through the treatment and first part of the withdrawal phase, then levelled out though the last three A2 phase tests. Graphic analysis revealed there was a steady trend decrease through the baseline and the intervention phase which ultimately levelled out though the withdrawal phase. Since the baseline showed a decreasing trend that was transported into the treatment phase it was difficult to know if the effect was in fact a result of the treatment. Subject #4 disliked the endurance test the most; therefore, it was difficult to encourage her motivatation to complete the test and to maintain her focus. She tended occassionally to pace out the endurance test so that she could have a strong finish. The consistent decrease in these measures may have reflected the subject's dislike toward this test; she contributed less than maximal effort each time and by starting at lower peak torque measures from the

Table 4-7. Subject #4 Phase Means and Percent Change Across Phases for Knee Flexion

VARIABLE		PHASE MEANS FLEXION			PERCENT CHANGE ACROSS PHASES AND SEM					
Peak Torque (ft. lbs.)		A1	B	A2	A1 to B	SEM	B to A2	SEM	A1 to A2	SEM
Speed	Side									
0.52	L-ND	43	49	49	13	1.52	0	0.00	13	1.52
0.52	R-D	61	63	61	3	0.45	-3	-0.45	0	0.00
1.05	L-ND	43	46	50	8	1.00	8	1.00	16	2.01
1.05	R-D	61	58	56	-5	-0.90	-4	-0.69	9	-1.59
2.09	L-ND	38	42	42	8	0.75	1	0.11	10	0.86
2.09	R-D	60	49	53	-19	-4.04	9	1.58	12	-2.46
3.14	L-ND	29	35	35	20	1.83	0	0.00	20	1.83
3.14	R-D	49	49	41	1	0.12	-16	-3.81	16	3.69
4.19	L-ND	25	31	31	21	1.75	0	0.00	21	1.75
4.19	R-D	43	43	37	-1	-0.07	-13	-1.64	13	1.71
5.24	L-ND	23	27	29	17	1.09	6	0.41	24	1.50
5.24	R-D	39	43	37	11	1.28	-14	-1.81	-5	0.53
Average Power (Watts)										
0.52	L-ND	21	22	20	5	0.66	-7	0.99	2	0.33
0.52	R-D	29	27	24	-8	-0.96	-11	-1.29	18	2.25
1.05	L-ND	39	39	38	1	0.14	-3	-0.28	-1	0.14
1.05	R-D	58	51	47	-13	-3.50	7	1.63	19	-5.13
2.09	L-ND	67	68	68	1	0.10	-1	0.07	0	0.03
2.09	R-D	104	84	88	-20	-3.87	5	0.76	-16	3.11
3.14	L-ND	72	68	82	6	-0.54	21	1.73	14	1.20
3.14	R-D	117	122	104	5	1.04	-15	-3.40	-11	2.36
4.19	L-ND	76	81	84	7	0.48	3	0.23	10	0.70
4.19	R-D	138	129	122	-6	-0.69	-6	-0.61	-12	1.29
5.24	L-ND	66	84	100	26	0.92	19	0.85	50	1.77
5.24	R-D	147	159	135	8	1.03	-15	-2.01	-8	0.99
Total Work (ft.lbs.)										
0.52	L-ND	40	46	44	16	2.34	4	-0.75	11	1.59
0.52	R-D	68	65	58	-4	-0.78	-11	-1.82	-15	-2.60
1.05	L-ND	41	43	43	5	0.51	1	0.13	6	0.64
1.05	R-D	67	63	57	-7	-1.43	9	-1.75	15	-3.17
2.09	L-ND	36	38	40	6	0.30	4	0.20	10	0.50
2.09	R-D	62	52	54	-17	-1.96	4	0.36	-14	-1.59
3.14	L-ND	27	31	34	14	1.21	11	1.13	27	2.34
3.14	R-D	47	52	46	11	1.93	-13	-2.51	3	-0.58
4.19	L-ND	22	26	28	17	1.12	8	0.60	26	1.72
4.19	R-D	43	44	40	1	0.07	-8	-0.99	-8	0.92
5.24	L-ND	16	22	27	42	1.57 #	20	1.09	71	2.66 *
5.24	R-D	38	43	38	12	1.57	-13	-1.82	-2	0.25
Torque Acceleration Energy (ft. lbs.)										
0.52	L-ND	0.68	0.55	0.50	-19	-0.91	9	0.36	-26	-1.28
0.52	R-D	1.03	0.55	0.65	46	4.10	18	0.86	-37	3.24
1.05	L-ND	1.38	1.35	1.15	-2	0.17	15	1.34	16	1.50
1.05	R-D	1.95	1.55	2.05	-21	1.55	32	1.94	5	0.39
2.09	L-ND	4.35	3.75	3.15	-14	1.17	16	1.17	28	2.34
2.09	R-D	5.10	4.70	4.70	-8	1.11	0	0.00	8	1.11
3.14	L-ND	5.88	4.85	5.45	-17	-0.81	12	0.48	7	0.34
3.14	R-D	8.35	7.80	6.95	7	0.77	11	1.19	17	1.36
4.19	L-ND	7.23	7.10	7.10	2	0.11	0	0.00	2	0.11
4.19	R-D	[illegible]30	10.00	9.70	3	0.43	3	0.43	6	0.86
5.24	L-ND	8.03	8.80	10.10	10	0.65	15	1.09	26	1.74
5.24	R-D	12.95	14.05	12.95	8	1.29	8	1.29	0	0.00
Average Power Endurance Test (Watts)										
3.14	L-ND	80	74	75	8	1.19	1	0.18	7	1.00
3.14	R-D	130	107	100	18	4.23	7	1.26	23	5.50
Total Work Endurance Test (ft. lbs)										
3.14	L-ND	493	583	638	18	3.92 #	9	1.16	29	3.08 *
3.14	R-D	911	924	808	1	0.29	13	2.68	11	2.59
Percent Fatigue Endurance Test (percent)										
3.14	L-ND	41	39	28	6	0.27	27	1.75	31	1.52
3.14	R-D	49	22	8	56	3.06	63	1.53	84	4.59

A1 - baseline mean B - intervention mean A2 - withdrawal mean

* - significant difference from B # - significant difference to post test value

Table 4-8. Subject #4 Phase Means and Percent Change Across Phases for Knee Extension

VARIABLE		PHASE MEANS EXTENSION			PERCENT CHANGE ACROSS PHASES AND SEM					
Peak Torque (ft. lbs.)		A1	B	A2	A1 to B	SEM	B to A2	SEM	A1 to A2	SEM
Speed	Side									
0.52	L-ND	80	80	76	0	-0.04	-5	-0.62	-5	0.66
0.52	R-D	108	117	109	8	1.51	-6	-1.37	1	0.14
1.05	L-ND	74	80	74	7	0.89	-7	-0.89	0	0.00
1.05	R-D	107	104	105	-3	-0.56	1	0.23	-2	-0.34
2.09	L-ND	62	72	69	16	1.94	-5	-0.70	10	1.25
2.09	R-D	96	89	96	-7	-0.99	8	0.99	0	0.00
3.14	L-ND	58	61	55	6	0.50	-10	-0.87	-4	-0.36
3.14	R-D	79	88	85	11	1.89	-3	-0.63	8	1.26
4.19	L-ND	52	54	49	4	0.45	-9	-1.00	-5	-0.55
4.19	R-D	71	73	67	2	0.37	-8	-1.36	-6	-0.99
5.24	L-ND	44	49	46	10	1.10	-5	-0.61	5	0.49
5.24	R-D	61	65	59	6	1.06	-9	-1.69	-4	-0.64
Average Power (Watts)										
0.52	L-ND	33	30	29	-8	-1.01	-3	-0.40	-11	-1.42
0.52	R-D	42	40	40	-5	-0.81	0	0.00	-5	0.81
1.05	L-ND	58	63	55	7	0.80	13	-1.51	-6	-0.71
1.05	R-D	85	78	78	-9	-1.21	0	0.00	9	-1.21
2.09	L-ND	102	110	97	8	0.83	-12	-1.31	-5	-0.49
2.09	R-D	160	138	143	-14	-1.85	4	0.46	-10	-1.39
3.14	L-ND	124	128	125	4	0.37	-3	-0.29	1	0.08
3.14	R-D	199	192	194	-4	-0.50	1	0.10	-3	-0.40
4.19	L-ND	158	151	141	-4	-0.37	-7	-0.53	-11	-0.90
4.19	R-D	239	236	190	-1	-0.17	-20	-2.53	-21	-2.70
5.24	L-ND	154	167	161	8	0.66	-4	-0.33	4	0.32
5.24	R-D	246	260	227	6	0.60	-13	-1.42	-8	-0.82
Total Work (ft.lbs.)										
0.52	L-ND	63	66	66	4	0.48	0	0.00	4	0.48
0.52	R-D	96	97	97	2	0.28	0	0.00	2	0.28
1.05	L-ND	61	67	63	9	1.04	-7	-0.81	2	0.23
1.05	R-D	97	96	94	-1	-0.22	-2	-0.36	-3	-0.58
2.09	L-ND	57	57	77	-1	-0.13	36	5.42	35	5.29
2.09	R-D	90	88	100	-3	-0.34	14	1.79	11	1.46
3.14	L-ND	51	53	52	5	0.47	-2	-0.19	3	0.28
3.14	R-D	84	82	84	-2	-0.28	2	0.37	1	0.09
4.19	L-ND	48	48	45	1	0.04	-7	-0.62	-7	-0.58
4.19	R-D	75	78	66	3	0.48	-15	-2.44	-12	-1.96
5.24	L-ND	38	44	42	15	1.27	-5	-0.44	10	0.83
5.24	R-D	64	71	62	11	2.00	-13	-2.61	-4	-0.62
Torque Acceleration Energy (ft. lbs.)										
0.52	L-ND	0.55	0.40	0.40	-27	0.88	0	0.00	-27	-0.88
0.52	R-D	1.03	0.75	1.10	-27	-1.24	47	1.58	7	0.34
1.05	L-ND	1.30	1.15	1.05	-12	-0.57	-9	-0.38	-19	-0.95
1.05	R-D	2.73	2.05	2.10	-25	-1.69	2	0.12	-23	-1.56
2.09	L-ND	4.08	2.35	2.80	-18	-0.84	-16	-0.64	-31	-1.48
2.09	R-D	6.73	4.80	5.50	-29	-2.41	15	0.88	-18	-1.53
3.14	L-ND	6.[illegible]	5.75	5.20	-5	-0.33	-10	-0.56	-14	-0.89
3.14	R-D	10.38	8.45	8.55	-19	-1.67	1	0.09	-18	-1.58
4.19	L-ND	10.[illegible]	8.60	7.30	-21	-1.72	-9	-0.58	-28	-2.29
4.19	R-D	14.30	13.00	10.00	-9	-0.58	-23	-1.35	-30	-1.93
5.24	L-ND	11.55	10.95	12.40	-5	-0.37	-5	-0.34	-10	-0.71
5.24	R-D	17.35	17.80	18.75	3	0.22	5	0.47	8	0.69
Average Power Endurance Test (Watts)										
3.14	L-ND	133	140	122	5	0.67	-13	1.74	-8	-1.07
3.14	R-D	202	198	178	-2	-0.44	-10	-2.15	-12	-2.60
Total Work Endurance Test (ft lbs)										
3.14	L-ND	1021	11[illegible]	1104	16	2.04	-7	-0.98	8	1.05
3.14	R-D	1622	1772	1649	[illegible]	2.01	-7	-1.65	2	0.36
Percent Fatigue Endurance Test (percent)										
3.14	L-ND	15	19	15	1	-0.02	-22	-0.32	-23	-0.34
3.14	R-D	28	14	9	-52	-1.70	37	0.58	-70	-2.27

A1 - baseline mean B - intervention mean A2 - withdrawal mean

start, kept the levels more constant over the test rather than exerting maximal effort from the beginning.

Effects of detraining

The detraining phase showed only a levelling out of the upward trend which appeared in the intervention phase for TW and TWE on the L-ND side. There was no decay of the measures back to the baseline conditions.

Discussion

From subject #4's results, there appeared to be minimal adaptation to the dependent variables and differential adaptation effects for sides and for extension versus flexion. The only significant adaptations seen were on TW at the fastest velocity only, and TW on the endurance test with small trend increases in PT seen on the L-ND side in flexion where she improved her performance at 3.14 rad sec^{-1}. Subject #4's non-dominant musculature was quite affected although she had experienced no difficulty completing the training and testing. The evident improvements seen could indicate the training effect existed in the slow to intermediate velocitites. The fast velocities may have been too difficult for changes to appear in PT, AP, and TAE which tend to be more correlated with high speed training (Perrin et al., 1989). Subject #4 improved on more endurance-related measures such as TW both at the fast velocity and the endurance test, which may have indicated that the "volume " of the contraction and the endurance capability were more likely the areas wherein improvements could be seen as a result of the fast velocity training. Improvement of the values of TW on the endurance test for the L-ND side appear to be related to the training performed during the study as this represented the endurance test. Had the training program been of longer duration, changes at the faster velocities may have been more significant. Perhaps if the study had been extended in time, significant changes at the fastest and slowest velocities may have been evident for PT, AP and TAE, by the end of the training program.

As noted with subject #1 and #2 there was no decrease in performance in the withdrawal phase of the study for the measures that showed improvement during the training phase. This may have occurred as a result of the same mechanisms explained in the discussions on subject#1 and #2.

The adaptations to the intervention on the L-ND side were different for flexion versus extension during the investigation. This differential adaptation was also seen in subject #3's limbs; consequently, mechanisms for this effect were explained in detail in the discussion of subject #3. The possible mechanisms could include 1) increased hamstring activity during extension; 2) selective hypertrophy of the type II muscle fibres in the spastic hamstrings; 3) improved inhibition of the quadriceps during knee flexion as opposed to no change of the hamstring inhibition through extension.

An additional consideration was the lack of effect in the R-D musculature. It may be possible that through her concurrent sprint training subject #4 was at the maximum level in terms of her neuromuscular adaptation prior to starting the fast velocity training program. It may be also possible that she was reluctant to undergo the intensity of training due to the hip injury in the early part of the training program.

In conclusion, there seemed to be a slight effect on the non-dominant hamstring musculature at the slow and intermediate velocities of testing in flexion for PT and for TW on the endurance test as a result of the training program although the same effect was not observed for the non-dominant quadriceps musculature in extension. The only adaptation at the faster velocities was on TW for the non-dominant musculature. The intervention did not have any effect on the dominant limbs musculature in either flexion or extension and possible mechanisms for this differential adaptation were previously discussed. The effect of fast velocity training was limited in this individual for both the L-ND limb and particularly the R-D limb. The fast velocity controlled training program had no effect on the adaptation to the velocity of training on any dependent variable.

SUBJECT #5

Subject Characteristics

Subject #5, a 28 year old male with spastic diplegia cerebral palsy, who is right dominant, volunteered to participate in the study. Subject #5 was referred to the study through the Cerebral Palsy Association of Alberta where he volunteers in its administration.

He ambulated with the assistance of a cane for balance. Prior to the study subject #5 participated in a one time per week exercise program where he performed some endurance training for his upper and lower body at the NAIT gym. He was encouraged to maintain this throughout the study and advised not to increase or decrease activities.

Subject #5 was very eager to participate and complied well with all testing and training procedures. Prior to the start of the testing he was given a 15-minute orientation and demonstration, and was given some practice trials in order to become familiar with the equipment and effort required during all testing and training sessions. During the baseline training phase familiarization and learning were effective, as evidenced on the first test when subject #5 could not develop torque at speeds 4.19 and 5.24 rad·sec^{-1}. He was able to develop torque on the subsequent tests which was fairly consistent. H[illegible] the fast velocities difficult especially for the hamstring musculature [illegible]k in comparison to his quadriceps through all speeds of testi[illegible]driceps ratios for peak torque ranged from 20-30% for the [illegible]peeds, and 30-40% for the fast velocities. For measures [illegible]l work, ratios ranged from 20-30% for the slow velociti[illegible]ermediate and fast velocities.

Subject #5 gave 100% effort through all testing and training sessions and was eager to perform well each time.

<u>Cybex Results</u>

Subject #5's graphic results are displayed on all graphs of the dependent measures in appendix B. The raw data of the phase mean calculations and the percent change computations for PT, AP, TW, TAE, APE, TWE, and PFE on concentric knee flexion and extension are shown in Tables 4-9 and 4-10, respectively.

Table 4-9. Subject #5 Phase Means and Percent Change Across Phases for Knee Flexion

VARIABLE		PHASE MEANS FLEXION			PERCENT CHANGE ACROSS PHASES AND SEM					
Peak Torque (ft. lbs.)		A1	B	A2	A1 to B	SEM	B to A2	SEM	A1 to A2	SEM
Speed	Side									
0.52	L-ND	31	28	29	-12	-0.99	5	0.40	-7	0.59
0.52	R-D	35	34	32	-4	-0.28	-4	-0.34	8	-0.62
1.05	L-ND	24	20	22	-17	-1.15	10	0.57	9	0.57
1.05	R-D	30	29	27	-4	-0.35	-7	-0.55	11	-0.90
2.09	L-ND	21	14	15	-32	-1.49	7	0.23	-27	1.26
2.09	R-D	22	22	24	-3	-0.26	12	0.88	8	0.61
3.14	L-ND	12	14	13	13	0.48	-4	-0.16	8	0.32
3.14	R-D	20	12	13	-41	-3.93	4	0.24	-38	3.69
4.19	L-ND	14	13	13	-4	-0.17	0	0.00	-4	0.17
4.19	R-D	15	15	14	-3	-0.15	-3	-0.15	-7	-0.30
5.24	L-ND	13	13	11	-6	-0.21	-16	-0.55	21	0.75
5.24	R-D	16	13	20	-20	0.98	54	2.11	23	1.13
Average Power (Watts)										
0.52	L-ND	11	10	10	-14	-0.99	0	0.00	-14	-0.99
0.52	R-D	12	11	11	-6	0.32	-5	-0.21	-11	0.54
1.05	L-ND	16	13	15	-23	-1.06	20	0.71	-8	-0.35
1.05	R-D	19	20	17	5	0.47	-15	-1.40	-11	-0.93
2.09	L-ND	21	13	17	-38	-1.10	27	0.48	21	-0.62
2.09	R-D	25	24	25	4	-0.19	2	0.10	-2	0.10
3.14	L-ND	12	15	13	25	0.36	-13	-0.24	8	0.12
3.14	R-D	27	12	11	-57	-2.93	-4	-0.09	-59	-3.02
4.19	L-ND	14	13	16	-4	-0.05	23	0.27	19	0.23
4.19	R-D	20	16	14	-18	-0.28	-16	-0.20	-31	-0.49
5.24	L-ND	18	17	14	-6	-0.05	-18	-0.16	-22	-0.21
5.24	R-D	24	16	23	-32	-0.64	44	0.60	-2	-0.04
Total Work (ft.lbs.)										
0.52	L-ND	19	20	20	4	0.28	-3	-0.19	1	0.09
0.52	R-D	24	24	23	-1	-0.07	-4	-0.26	-5	-0.33
1.05	L-ND	15	13	16	-14	-0.51	24	0.77	7	0.26
1.05	R-D	20	22	19	8	0.48	-12	-0.79	-5	-0.32
2.09	L-ND	10	7	9	-26	-0.33	21	0.20	-11	-0.13
2.09	R-D	14	14	14	0	0.00	0	0.00	0	0.00
3.14	L-ND	4	5	4	43	0.48	-20	-0.32	14	0.16
3.14	R-D	10	4	4	-58	-2.12	-13	-0.19	-63	-2.31
4.19	L-ND	3	3	4	0	0.00	33	0.30	33	0.30
4.19	R-D	5	4	4	-20	-0.28	-13	-0.14	-30	-0.42
5.24	L-ND	4	3	3	-14	-0.12	0	0.00	-14	-0.12
5.24	R-D	5	4	5	-26	-0.41	43	0.50	5	0.08
Torque Acceleration Energy (ft. lbs.)										
0.52	L-ND	0.40	0.40	0.55	0	0.00	38	1.09	38	1.09
0.52	R-D	0.43	0.45	0.50	6	0.22	11	0.43	18	0.65
1.05	L-ND	1.05	0.95	0.80	-10	-0.67	-16	-1.00	-24	-1.67
1.05	R-D	0.90	1.00	0.90	11	0.39	-10	0.39	0	0.00
2.09	L-ND	2.33	2.05	2.05	-12	-0.54	0	0.00	12	0.54
2.09	R-D	2.18	2.10	2.25	-3	0.21	7	0.42	3	0.21
3.14	L-ND	2.30	2.80	2.90	22	0.40	4	0.08	26	0.48
3.14	R-D	3.18	2.50	2.35	-21	-0.95	-6	-0.21	-26	1.16
4.19	L-ND	3.38	2.80	2.75	-17	-0.49	-2	-0.04	-19	0.53
4.19	R-D	3.50	3.60	3.40	3	0.14	-6	0.29	-3	0.14
5.24	L-ND	3.75	3.60	3.30	-4	-0.13	-8	0.25	12	-0.38
5.24	R-D	5.83	3.90	5.60	-33	-2.26	44	2.00	-4	0.26
Average Power Endurance Test (Watts)										
3.14	L-ND	19	10	17	-48	-1.69	65	1.19	14	0.50
3.14	R-D	27	20	18	-26	-1.26	-10	-0.36	-34	1.62
Total Work Endurance Test (ft. lbs)										
3.14	L-ND	69	37	74	-47	0.70	101	0.79	6	0.09
3.14	R-D	131	95	61	-27	0.83	36	0.80	54	1.63
Percent Fatigue Endurance Test (percent)										
3.14	L-ND	49	53	36	7	0.42	32	2.03	-28	1.61
3.14	R-D	31	34	77	8	0.28	130	4.93	148	5.21

A1 - baseline mean B - intervention mean A2 - withdrawal mean

Table 4-10. Subject #5 Phase Means and Percent Change Across Phases for Knee Extension

VARIABLE		PHASE MEANS EXTENSION			PERCENT CHANGE ACROSS PHASES AND SEM					
		A1	B	A2	A1 to B	SEM	B to A2	SEM	A1 to A2	SEM
Peak Torque (ft lbs.)										
Speed	**Side**									
0.52	L-ND	97	97	112	0	0.00	16	2.40	16	2.40
0.52	R-D	117	124	108	5	1.14	-13	-2.83	-8	-1.69
1.05	L ND	89	84	94	-6	-0.85	11	1.53	5	0.69
1.05	R-D	94	95	116	1	0.19	22	3.16	24	3.34
2.09	L-ND	75	62	78	-17	-2.54	26	3.19	4	0.65
2.09	R-D	80	73	95	-9	-0.99	30	3.10	19	2.11
3.14	L ND	60	54	63	-11	-0.97	18	1.37	5	0.40
3.14	R-D	58	59	59	2	0.21	-1	-0.10	1	0.10
4.19	L-ND	49	45	51	-10	-0.95	13	1.21	3	0.25
4.19	R-D	47	51	59	7	0.89	16	1.97	24	2.78
5.24	L-ND	46	39	45	-16	-1.77	14	1.35	-4	0.43
5.24	R-D	45	39	45	-14	-1.77	15	1.69	-1	-0.07
Average Power (Watts)										
0.52	L-ND	40	37	45	-8	-1.21	22	3.24	13	2.02
0.52	R D	41	44	41	7	1.11	-7	1.22	-1	-0.10
1.05	L-ND	72	63	76	-12	-1.65	21	2.46	6	0.80
1.05	R-D	71	68	79	-5	-0.59	16	1.84	11	1.26
2.09	L-ND	116	96	127	-17	-1.92	32	3.01	10	1.09
2.09	R-D	119	108	140	-9	-0.87	30	2.63	18	1.79
3.14	L-ND	123	107	129	-13	-1.34	21	1.82	5	0.47
3.14	R-D	116	121	120	4	0.33	-1	-0.07	3	0.26
4.19	L-ND	132	114	135	-13	-0.94	18	1.08	2	0.15
4.19	R-D	134	129	139	-4	-0.28	8	0.55	4	0.28
5.24	L-ND	125	113	136	-10	-0.64	20	1.19	8	0.54
5.24	R-D	117	117	132	0	0.01	12	0.63	13	0.64
Total Work (ft.lbs.)										
0.52	L-ND	68	73	85	7	0.95	17	2.53	24	3.48
0.52	R-D	81	90	86	10	1.53	-4	-0.74	5	0.79
1.05	L-ND	66	65	77	-1	-0.14	18	2.08	16	1.95
1.05	R-D	74	74	86	0	-0.04	16	2.14	16	2.10
2.09	L-ND	54	50	65	-7	-0.99	30	3.97	21	2.98
2.09	R-D	64	60	78	-6	-0.56	30	2.69	22	2.13
3.14	L-ND	39	38	44	-4	-0.33	17	1.22	12	0.89
3.14	R-D	42	45	45	7	0.51	0	0.00	7	0.51
4.19	L-ND	33	31	38	-5	-0.31	21	1.15	15	0.84
4.19	R-D	37	36	40	-5	-0.37	11	0.85	6	0.48
5.24	L-ND	26	25	30	-3	-0.17	20	1.10	17	0.94
5.24	R-D	32	27	32	-14	1.24	19	1.38	2	0.14
Torque Acceleration Energy (ft. lbs.)										
0.52	L-ND	0.85	0.55	0.75	-35	-1.76	36	1.17	-12	-0.59
0.52	R-D	0.65	0.65	0.60	0	0.00	-8	-0.23	-8	-0.23
1.05	L-ND	2.33	1.70	2.10	-27	-2.38	24	1.52	-10	-0.86
1.05	R-D	1.98	1.55	1.25	-22	-1.06	-19	-0.75	-37	-1.81
2.09	L-ND	6.15	4.20	5.55	32	-2.26	32	1.56	-10	-0.70
2.09	R-D	4.28	4.15	4.45	-3	-0.16	7	0.38	4	0.22
3.14	L-ND	8.65	7.35	8.80	-15	-1.32	20	1.47	2	0.15
3.14	R-D	7.98	7.75	7.50	-3	-0.20	-3	-0.22	-6	-0.41
4.19	L-ND	12.00	9.40	11.40	-22	-2.15	21	1.65	-5	-0.50
4.19	R-D	10.63	10.65	11.00	0	0.01	3	0.16	4	0.17
5.24	L-ND	14.20	11.90	14.15	16	1.41	19	1.38	0	-0.03
5.24	R-D	11.58	12.15	11.95	5	0.28	-2	-0.10	3	0.19
Average Power Endurance Test (Watts)										
3.14	L-ND	131	117	147	-11	-1.47	26	2.99	12	1.52
3.14	R-D	144	137	145	5	-0.80	6	0.88	1	0.08
Total Work Endurance Test (ft. lbs)										
3.14	L-ND	850	879	1076	3	0.37	22	2.50	27	2.87
3.14	R-D	994	874	1027	-12	1.62	18	2.06	3	0.44
Percent Fatigue Endurance Test (percent)										
3.14	L-ND	2	3	22	[illegible]	[illegible]	[illegible]	1.50	856	1.52
3.14	R-D	13	32	33	[illegible]	[illegible]	5	0.17	164	2.36

A1 - baseline mean B - intervention mean A2 - withdrawal mean

Effects of training and detraining

There were no significant improvements noted on any dependent measure at any velocity as a result of the fast velocity controlled training program. Instead, measures of PT, AP, and TW in flexion with the R-D side displayed decreases in performances across the treatment phase at 3.14 rad·sec^{-1} by -41% (-3.93 SEM), -57% (2.93 SEM), -58% (-2.12 SEM), respectively to total losses of -59% (3.02 SEM) and -63% (2.31 SEM) for AP and TW.

Despite the lack of objective improvements seen in subject #5's data, he verbalized many subjective improvements as early as one month into the training program. Subject #5 reported that his ability to walk stairs improved as he felt more coordinated while ascending them. He also reported he was able to break into a run without tripping and falling down and that he experienced increased walking endurance as he could walk farther without his cane. He also noted improved balance and ability to squat and lunge to the ground to retrieve objects.

Discussion

From subject #5's results there appeared to be no effect of the intervention on any of the dependent measures in both flexion and extension. Out of all the subjects in the study, subject #5 was the most affected by CP. Both his quadriceps and hamstrings were small and quite spastic. Throughout the testing he had the most difficult time with faster speeds as evidenced in the first test where he could not attain the fast velocities to develop torque in flexion or extension.

It may have been possible that due to the severity of dysfunction seen in subject #5 the spastic musculature atrophy of type II muscle fibres (Castle et al., 1979; McComas et al., 1978) was substantial; thus he did not have the ability to generate enough torque at the fast velocity to observe a difference as a result of the training. Additional influencing factors could have been the impaired motor unit activation pattern and firing rate seen in spastic muscle (El-Abod et al., 1993; Rosenflack & Andreasson, 1980; Tang & Zrymer, 1981) resulting in the inability of the prime movers to activate enough motor units to improve the measures at these velocities of testing. The speed of training may also have been too fast for the hamstrings and quadriceps to build up sufficient tension to stimulate a training effect (Knutsson & Martensson, 1980).

Involuntary cocontraction of the antagonist muscle groups in both flexion and extension may have prevented a training effect especially at the faster velocities. As noted by many authors the cocontraction of the antagonist muscles increased with velocity of movement through the deficits in reciprocal inhibition/facilitation (Berbrayer & Ashby, 1990; Leonard et al., 1990; McLellan, 1977; Mizrahi & Angel, 1979; Myklebust et al., 1982; and Sahrmann & Norton, 1977). Cocontraction of spastic hamstrings and quadriceps could have effected the development of torque. power and work measurements, by not allowing the limbs to accelerate fast enough to apply sufficient resistance to the lever arm to achieve a training effect. This cocontraction was obvious during some sessions of training where the quadriceps would become spastic, rendering subject #5 rigid in extension. Subject #5 found it most difficult to develop torque and power in flexion due to the spasticity evident in the quadriceps.

Despite the fact that no objective improvements were noted, subject #5 reported many subjective improvements as a result of the training, an indication that the observed training effect may have been beneficial in other functional measures such as speed of movement, walking speed, gait analysis, stair climbing speed and gross motor coordination. This notion is supported by evidence that improved motor function can be achieved through repetitive practice trials with no resistance (Hobart et al., 1975; Kottke, 1980; Payton and Kelley, 1972; Person, 1958).

In conclusion, fast velocity training did not elicit training effects on the dependent variables measured in subject #5 for various possible neuromuscular and muscular reasons. Despite the fact that no objective increases were noted, significant subjective gains were reported. This suggests that the training effect from fast velocity training may not be realized in the variables measured but in other unmeasured variables such as gross motor skills.

2. GENERAL DISCUSSION

Examination of the subjects' results revealed that adaptation to fast velocity controlled training in this population is not systematically consistent and is quite complex due to the differential adaptations of dominant versus non-dominant sides and flexion versus extension. Depending on the type of CP one has and the severity of the dysfunction, adaptation to this type of training could differ. Due to the wide variability between and within subjects, generalities would be difficult to make about the group of people who participated in this study, although some commonalities were apparent.

Despite spastic musculature all subjects were able to complete all required tests at all velocities tested. The reliability/consistency of the measurements from occasion to occasion were good for the slow to intermediate velocities and decreased as the velocity increased which was consistent with non-disabled research (Perrin et al., 1993). Non-dominant musculature tended to be more variable than dominant on most measures, as evidenced through examination of the SEM values where for the most part the non-dominant side exhibited higher SEM's for flexion and extension. Most of the subjects displayed good stability and reliability as demonstrated through low SEM for PT, TW, and TAE both in flexion and extension, although extension was more stable than flexion especially at the velocities 0.52, 1.05, 2.09, and 3.14 rad·sec^{-1}(in extension most measures were within ± 5-7% of the mean baseline scores). AP tended to be more variable at the faster velocities especially on the non-dominant side for knee flexion and for the dominant side for knee extension. This was consistent with the works of Tripp and Harris (1991) and Watkins et al. (1984) who tested individuals with spastic hemiparesis and found that isokinetic testing can yield reliable results for peak torque at slow and intermediate speeds. The primary limitations in the previous work performed on individuals with spastic paresis involved the fact that they were not assessed at fast angular velocities and on other dependent measures such as total work average power and muscular endurance. Measurements for AP and TW for subject 1 through knee flexion were lacking stability at the faster velocities (5.24

and 4.19 rad·sec^{-1} with variability of ± 10-15%). Unfortunately, the decision to begin the intervention phase first was made due to the threat of subject dropout if the training program did not start. Subjects #2, #3, and #4 indicated good stability of most measures with some increased variability of the measurements at the faster velocities. Subject #5 showed increased variability of most measures in flexion following the first four tests, the first test results having indicated that he was able to develop torque, power and work at the fast velocities in both flexion and extension. During subsequent tests 2, 3, 4, and 5 he adapted to the speed of testing and was able to develop torque at the faster velocities. After the first four testing sessions, subject #1 began the training program and one week later, subject #2 started the training program; then, subjects #3, #4, and #5 were tested a fifth time to complete their baselines and begin the intervention phase one week apart after subject #2 started the training phase. Even after the five baseline testing sessions subject #5's measurements were not entirely stable (especially the flexion measurements at 3.14, 4.19, and 5.24 rad·sec^{-1} for peak torque, average power and total work) but due to the length of the ensuing phases a decision was made to begin the intervention phase of the study on account of the threat of researcher contrictions and subject attrition. Although this was not an ideal situation for single subject research it was hoped that the resistance training program would show a sufficiently strong effect to improvements beyond the baseline data.

Following the baseline data collection it was determined that measurements of PFE in flexion and extension of the endurance test were not suitably stable for subjects #3 and #5. Relative endurance measures were difficult to obtain accurate reliability even in the non-disabled population as noted by Montgomery et al. (1989). More reliable were the absolute measures of endurance such as TWE and APE which was consistent with research in the non-disabled population (Burdett and Swearigan, 1987 and Montgomery et al., 1989). During the evaluation of the baseline stability it was important to realize because of the nature of t' lependent variables measured and the subject population, desirable stability o. ..ie baseline measures would not always be possible due to intrasubject variability and motivation of the subjects, especially with regard to the endurance test.

Previous experience in sport or resistance training was a factor in familiarization of the testing procedure and foreknowledge of the effort which would be required during the testing and training sessions. Subject #1, #4, and #5 had not previously participated in resistance training programs that required maximal effort; therefore, they found the testing and training quite stressful at times. A thorough familiarization and orientation session for subjects must accompany and preface this type of study. The procedures in this study reinforce those found in Holland et al. (1994) in that subjects with CP required at least one introductory session on the equipment before accurate and reliable data was collected.

The protocol used for testing was effective in eliciting reliable measures. The use of maximal practice repetitions immediately prior to the specific velocity tested, proved to be very effective and was well received by the participants. For the particular population in this study, it was apparent that a familiarization with the upcoming test velocity was very beneficial. Some subjects found it difficult switching from a slow velocity of testing to a fast velocity without experiencing it first; thus, having the practice repetition was helpful in readjusting the system to meet that speed. The randomly-assigned testing order for subject #2 and #3 consisted of switching from 0.52 rad$\cdot$sec^{-1} to 5.24 rad$\cdot$sec^{-1} which they initially found difficult. However, maximal practice repetitions were helpful in resetting their anticipation of the testing velocity. In this population strict standardization of the protocol and testing conditions was vital in obtaining reliability and consistency between repeated measurements on the same person. The protocol used in this study utilized visual feedback (VF) during muscle performance testing by allowing the subjects to watch the real-time display of the gravity-corrected muscular torque measures. It has been shown by Baltzopoulos et al. (1991), VF such as a real-time display on a computer screen during slow velocity (1.05 rad$\cdot$sec^{-1}) isokinetic testing had a positive effect on maximum torque generated when compared to no VF; however, no positive effect of VF was evident during fast velocities (3.14

rad sec^{-1}). Baltzopoulos et al. (1991) maintained the effectiveness of visual feedback decreased as the velocity of movement increased and/or the range of movement became less. In this investigation the use of VF remained constant through all testing and training sessions; however, the effect of constant VF on the data collected is unknown. It was considered that the effect of VF on the conclusions drawn was minimal by the fact that the movement of knee flexion and extension through a full range of motion required little if no motor learning in this subject population. However, without further investigation into the effects of VF on data as collected in this study the researcher cannot discount the possible effects it may have had on the subjects' muscular performance.

Single subject designs must be used with this population as there existed such inter and intraindividual variability that each subject must serve as their own control. The only drawback as noted in this study, was that effects sometimes needed to be considerably substantial to be considered absolute changes; therefore, the risk of making a type II error was increased. Through the use of SEM's and percent changes across phases in combination with visual inspection of the graphic data, the reseacher reached educated and conclusive evidence. Another drawback encompassed the withdrawal period in this study in that it may have been too short to see dramatic decreases in measurements through this phase of the study. Although it was felt that the ABA multiple baseline design used in this study had a effective application, lengthening the withdrawal phase to see regression back to the baseline conditions may have increased its value and strength.

A consistent type of adaptation to a specified velocity or velocities was not found. Although it appeared that most of the individuals, with the exception of subject #5, showed a training effect in flexion most of the time, the subjects varied to which velocity they adapted and which measure predominantly improved. The differential adaptation seen in flexion as opposed to extension could be related to muscle fibre type and the selective activation or deactivation of the flexors and extensors respectively, during reciprocal flexion and extension or due to the seated position during training. It would be interesting to observe if a more consistent adaptation of the knee extensors would have occurred if the subjects had trained in the semi-reclined or supine position where the quadriceps tended to be put on more stretch and the hip extensors and hamstrings were less prone to a dynamic stretch during the extension phase of movement. What was lacking in this study was examination of the effect this training program had on individual spasticity. The differential adaptation seen in this study suggested the need for investigation that would quantify the level of spasticity of the flexors and extensors as a result of this type of training, which may have produced more definitive reasons for such responses to fast velocity controlled training in these individuals.

Due to the duration of the study and some of the training effects seen, adaptations of the neurological and neuromuscular system may have played an important role as they have in the non-disabled population (Hakkinen et al., 1983; Moritani and Devries, 1979). Improvements seen in subject #1, #2, #3, and #4 may have been a result of the improved reciprocal inhibition of the antagonist as noted by McCubbin and Shasby (1985) and Sale (1986, 1987), as a neural change accompanying strength improvements (Bell and Wenger, 1992). Other positive adaptations which may have occurred were the improved recruitment and synchronization of motor units as outlined by McCubbin (1994) and increased size of the type II fibre area in the adapating exercising muscle, although further specific investigation is required to elucidate the true mechanism.

Another interesting result of the study was that none of the three subjects (#1, #2, and #4) exhibited decay of the training induced changes when training was discontinued for 10 weeks. As discussed previously, this may have been attributed to the prolonged effect and slow reversibility in isokinetic training as noted by Cote et al. (1988) where there was an metabolic enzymatic increase resulting from isokinetic training that did not diminish with 50 days of detraining; also, that responses seen in PT and enzymatic activity were clearly long-term adaptations to the training stimulus. This observation was further supported by Thorstensson (1977) and Houston et al. (1983) who found that responses to isokinetic training were present five months and 12 weeks, respectively, without training stimulus. The withdrawal phase which existed in this study may have been too short to see a detraining effect on the variables measured and subjects tested and trained. Although this effect was also not seen in subject #3, the reason for this difference remains unknown.

Relationships between variables tested and velocity were consistent with that found in the non-disabled population. An increase in velocity resulted in a decrease in peak torque and total work, along with an increase in average power (Heyward, 1988; Moffroid et al., 1969; Montgomery et al., 1989; Thompson et al., 1993). Of the dependent variables used in this study, it was found that the researcher must look beyond PT as the sole area in which subjects with CP could improve as a result of training. Other measures such as TW, AP, and TAE are extremely important in quantifying improvement as a result of this type of training program. In addition, it may have proved useful to include more multi-joint and gross motor tests in the study, to see if the effects from a similar fast velocity training program are evident in other measures in the absence of objective changes on the dependent measures, as in the case of subject #5.

One of the premier limitations to this study which may have prevented more consistent adaptation to the training program, was the length of the training phase. Due to the design of the study, lengths of all phases must be considered when subject compliance and adherence are important considerations. The eight weeks allotted to the training program may not have been long enough to indicate true improvements as a result of fast velocity controlled training, which is reinforced by Perrin et al. (1989). Because of the neurological and muscular deficits evident in individuals with CP, longer training programs may be advantageous in order to elicit a more significant and consistent training effect.

In summary, although no consistent adaptations were noted for the individuals who participated in this study there were many positive observations. Individuals with CP were able to complete the speeds of testing and training, for the most part with adaquate consistentcy. Knowledge was gained with regard to procedures in testing and training and responses of persons with CP to this type of training program and the period of detraining

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CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

A single subject, ABA multiple baseline across subjects research design was used to determine the response of five individuals with CP to fast velocitiy controlled resistance training of the lower extremities on concentric knee flexion and extension. All subjects, except subject #5, showed various levels of improvements but were not consistent in their adaptation to different velocities of testing, to flexion versus extension and to the legs which were trained. Subject #5 did not improve objectively over the course of the investigation though some subjective increases were reported. Within the subjects who noted improvements, the increases were differential between sides and between flexion and extension. Various proposed mechanisms for such results were explained.

Conclusions

The initial question of this thesis asked what would be the response of individuals with CP to a fast velocity controlled training program on six selected angular velocities and a test of endurance and would these individuals respond by adapting to the particular velocity at which they trained. According to the results of the individuals it was determined that there was no consistent effect in terms of their improvement of each variable at the different velocities and to which leg they improved on or which movement they improved on, flexion or extension. When they improved, most subjects experienced increases in the dependent variables generally at the six to eight week mark of the training program. Those improvements were speculated to be a result of both neural and muscular factors as documented in the non-disabled population. Only one of the four who showed improvement significantly lost their training effect in the withdrawal phase. It was speculated that the detraining effect could take much longer than the 10 weeks given in the withdrawal phase of the study. Also, the level of activity and testing schedule may have contributed to the lack of decrease in the withdrawal phase through a maintenance effect.

In conclusion, a fast velocity controlled resistance training program had limited effect in improving torque, work, and power measures at various velocities in these individuals with CP. Adaptations observed were primarily in knee flexion with limited effect on knee extension. The adaptation documented in the subjects of this study were highly individual and differential in muscle performance in flexion and extension as well as in the dominant and non-dominant sides. The training program was also limited in its effect on muscular endurance measures. Fast velocity controlled training may have some positive effects for some people in certain neuromuscular relationships and may prove useful for enhancing sport and the performance of everyday tasks. However, lack of change in some parameters after training suggests that fast velocity training may not be an effective training stimulus for some individuals with CP.

Recommendations

It is highly recommended that a single subject design be employed when studying this population. There was so much interindividual and intraindividual variability, that the task of trying to develop a homogeneous group for conventional research designs became virtually impossible.

Along with the results of this study came further research recommendations; 1) To try to ascertain some consistency of adaptations to velocity controlled resistance training in individuals with CP. Multi-replication of the methods employed was recommended on people with similar types of CP to the subjects in this study; 2) Training individuals at different velocities of training could elucidate any velocity specific adaptations to velocity controlled resistance training in this population of subjects; 3) It would interesting to study if these individuals adapted better to more functional multi-joint training with devises such as the seated leg press made by Hydra-Fitness Industries rather than single jointed leg flexion and extension; 4) Additional measurements such as spasticity and cocontraction through the use of EMG is warranted to elucidate the neural adaptation to this type of training in the CP population; 5) Assessing gross motor skills as a result of this type of training program would have helped in evaluating the nature of any improvements observed, as the variables collected in this study may have been only part of the picture of the adaptation to this type of training in individuals with CP; 6) Lengthening the training program to 12-16 weeks may have provided a stronger more consistent training effect, and a longer withdrawal phase may have confirmed the time and presence of the consistent decay of the training effect in order that more specific conclusions could be made; 7) Different training protocols may have been more effective in eliciting a more significant training effect as a result of the fast velocity controlled training program. Possibly a combination of coupled concentric and eccentric velocity controlled training would have shown superior results from training as opposed to only concentrtic training. This method in addition to only eccentric training should also be studied, to ascertain the responses noted; 8) Further investigation into the reciprocal inhibitory/facilitory relationships, muscle fibre type adaptation, enzymatic changes, and neural factors which contributed to the training effect would help uncover the nature of the training effects which appeared as a result of the fast velocity training in individuals with CP; 9) Training subjects in a semi-reclined or supine position could have facilitated extension measure improvement and decreased the effect of hip extensor spasticity.

It was highly recommended that attempts be made to proceed with these recommendations in future research projects.

APPENDIX A

CP-ISRA FUNCTIONAL PROFILE OF CLASS 5

Type: Diplegic - Moderate involvement

This individual may require the use of assistive devises in walking but not necessarily when standing or throwing. A shift of the centre of gravity may lead to loss of balance. A Triplegic may appear in this Class.

Lower Extremities - Spasticity Grade 3. Involvement of one or both legs which may require assistive devises for walking. A Class 5 athlete may have sufficient function to run on the track. If function is insufficient Class 4 may be more appropriate.

Balance - Usually has normal static balance but exhibits problems in dynamic balance eg. attempting a spin or throwing forcefully.

Upper Extremities - This is an area where variation occurs. Some moderate to minimal limitation in the upper extremities can often be seen particularly when throwing, but strength is within normal limitations.

Hand Function - Normal cylindrical/spherical, opposition and prehensive grasp and release in the dominant hand is seen in all sports.

TRACK Some athletes with diplegia Spasticity Grade 3 and 2 are able to run.

FIELD The major problem is dynamic balance and function when standing in sport or without assistive devises. Class 5 athletes may use a run up in field events.

SWIMMING Symmetrical shoulder girdle function and unimpaired trunk potential. Range of motion of the hip and leg movements is greater in Class 4 swimmers. Knee and dorsiflexion of the ankle involvement are less than Class 4 swimmers. Basic reciprocal leg movements possible but these do not make a positive kick for propulsion. Basic functional dives and turns may be possible.

APPENDIX A

CP-ISRA FUNCTIONAL PROFILE OF CLASS 7

Type - Hemiplegic

This is a class for the truely ambulant hemiplegic athlete. Class 7 athlete has spasticity Grade 3 to 2 in one half of the body. They walk without assistive devises but often will limp due to spasticity in the lower limb. Good functional ability in the dominant side of the body.

Lower Extremities - Hemiplegia Spasticity Grade 3 to 2. Dominant side has better development and good follow through movement in walking and running. Moderate to minimal athetoids do not fit into this Class.

Upper Extremities - Arm and hand control are only affected in the non-dominant side. There is good functional control on the dominant side.

TRACK In walking the Class 7 athlete demonstrates a limp on the affected side. While running the limp may disappear almost totally. The reason is that in running the leg support during stance phase is on the ball of the foot. In walking the stance begins with a heel strike. This is the most diificult action for persons with spatic paresis. During walking the affected arm is almost always in the wing-like position. During running both arms are bent at the elbow. This means that during running there is less difference between the arm positions. Consequently, during running the hemiplegic athlete during running demonstrates an almost non-disabled pattern of movement. This means that a good running action does not transfer a Class 7 athlete to Class 8.

FIELD In throwing events the hemiplegic athlete often demonstrates hip flexion on the affected side instead of hyperextension. Trunk rotation during a throwing action also indicates a loss of fluency. In javelin throwing the transfer from run up to throwing phase demonstrates these difficulties clearly.

SWIMMING Notable asymetry of stroke function. Swimmers exhibit hemiplegic spasticity signs and are unlikely to be capable of symmetrical breast stroke. Very slightly affected hemiplegics will be classified into Class 8.

CP-ISRA FUNCTIONAL PROFILE OF CLASS 8

Minimal Involvement

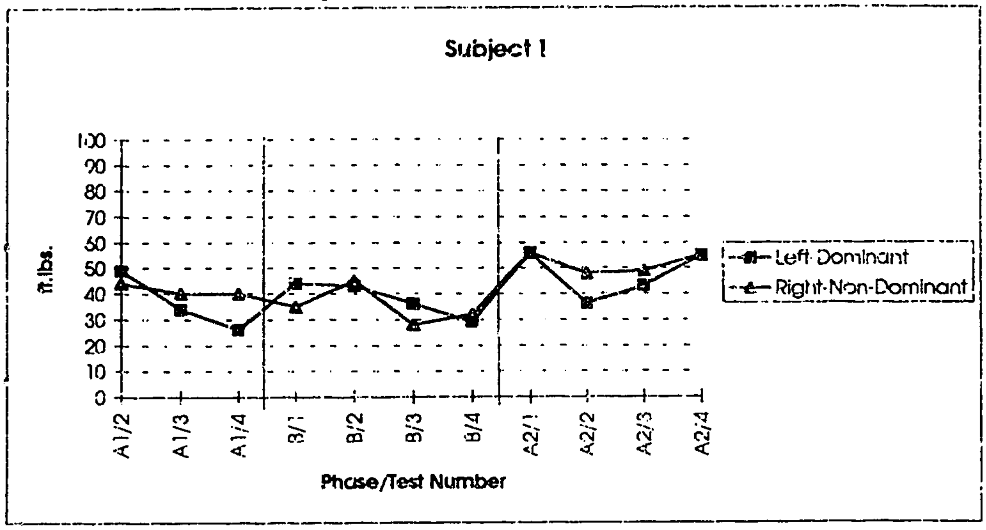
This Class is for the minimally affected diplegic Spasticity Grade 2 to 1; Hemiplegic Spasticity Grade 2 to 1; Monoplegic; Minimal athetoid/ataxic athlete.

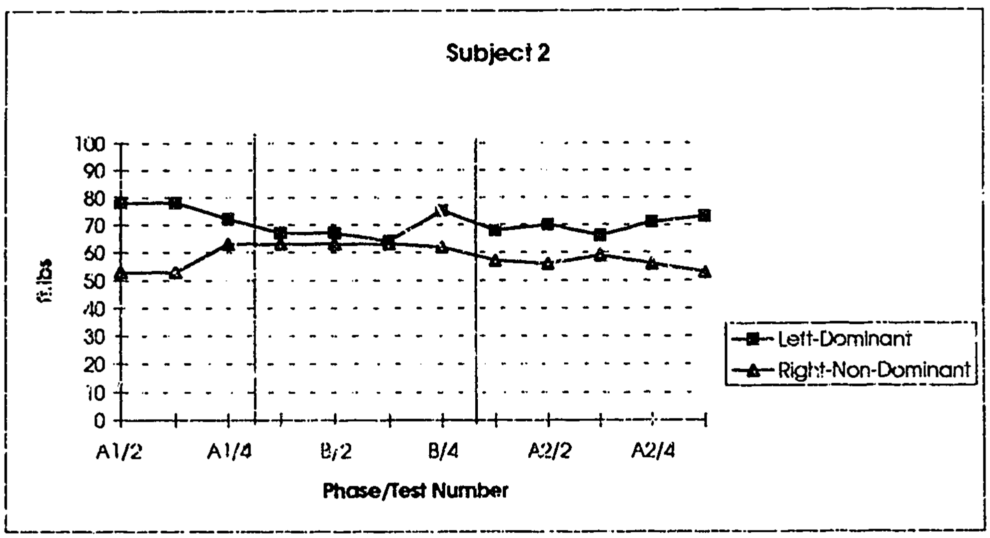
Source: (1993-1996). Classification and Sport Rules Manual 6th Edition. Cerebral Palsy - International Sports and Recreation Association. pg 34-38.

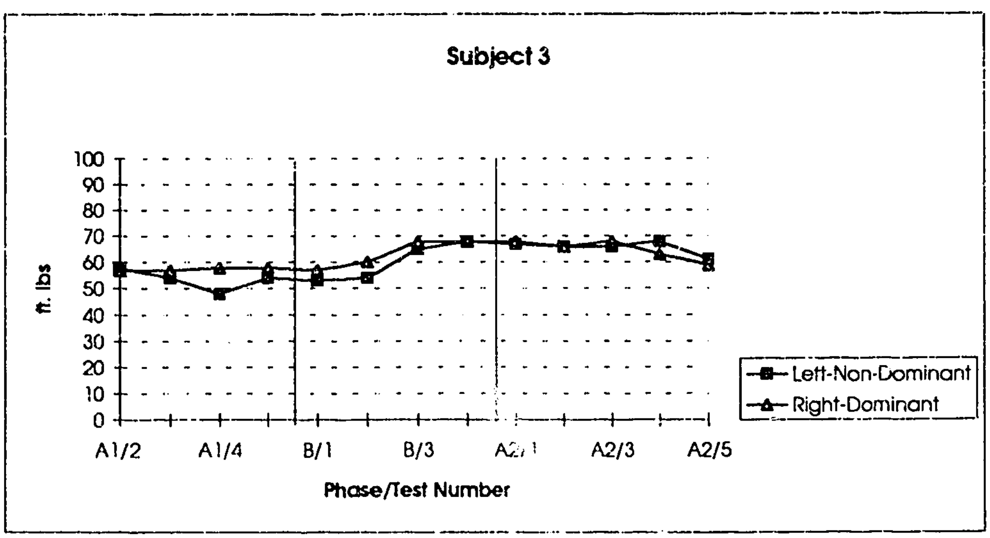
APPENDIX B

ALL SUBJECTS GRAPHICAL CYBEX DATA

Peak Torque Flexion 0.52 rad·sec^{-1}

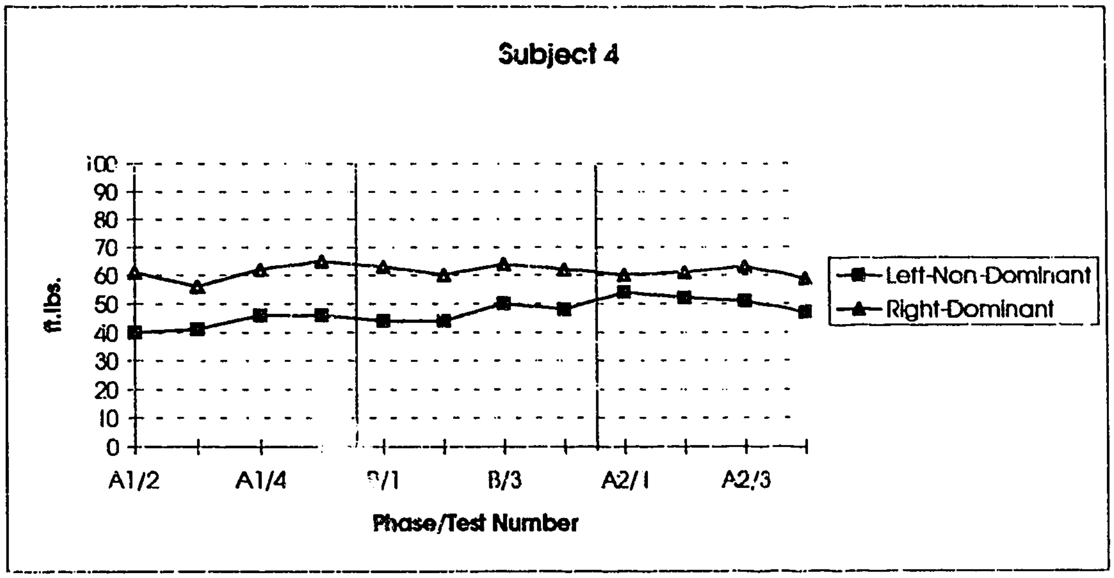


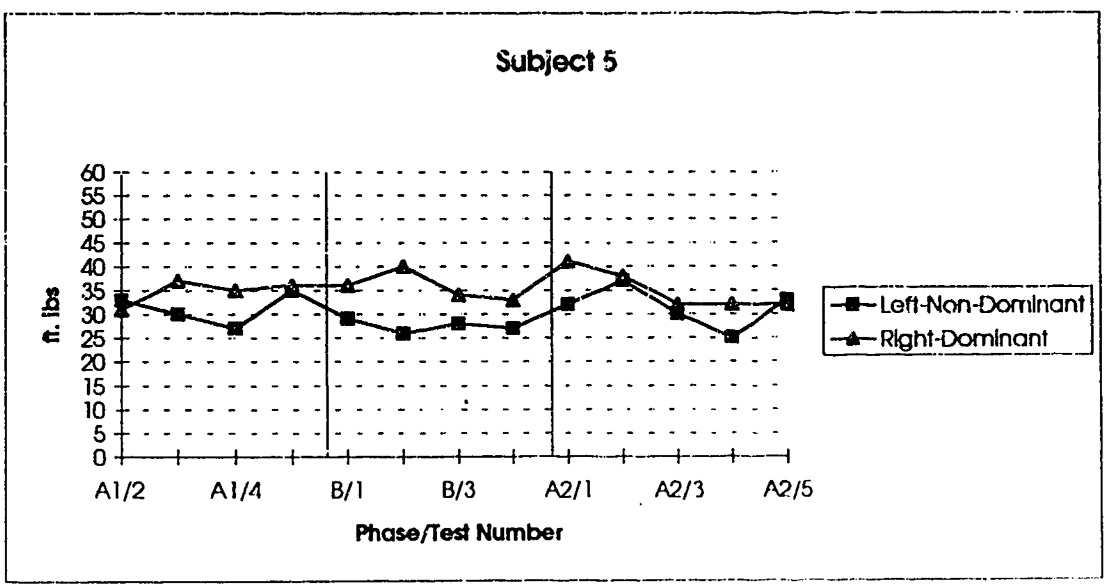




A1 - Baseline Phase B Intervention Phase A2 - Withdrawal Phase

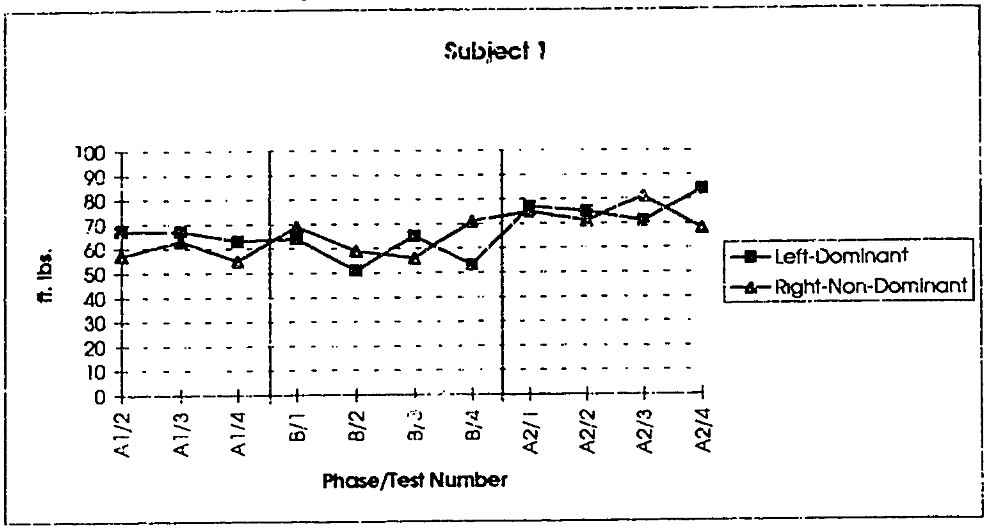
Peak Torque Flexion 0.52 rad·sec⁻¹

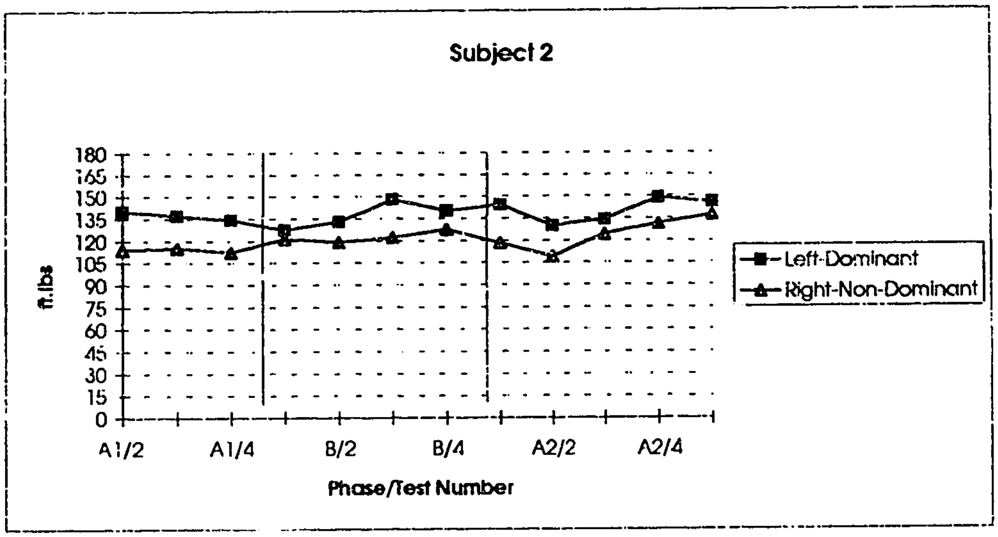


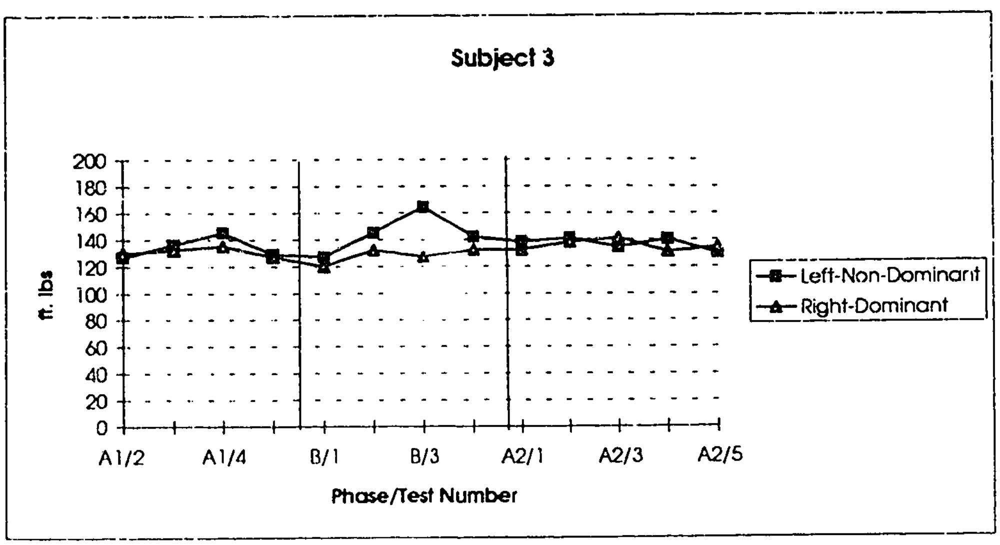


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Peak Torque Extension 0.52 rad·sec^{-1}

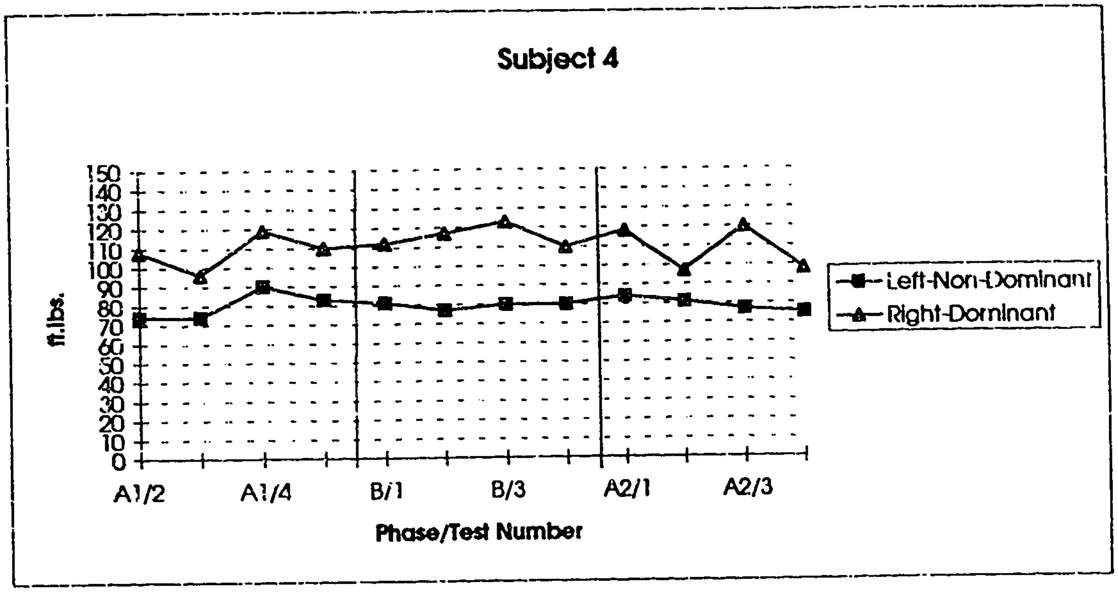


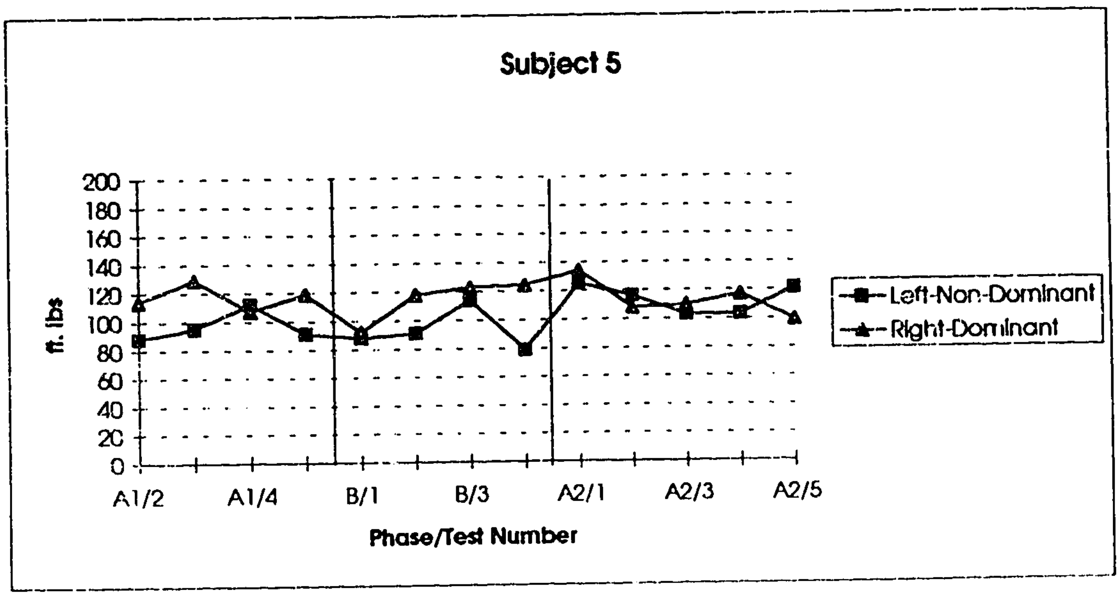




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

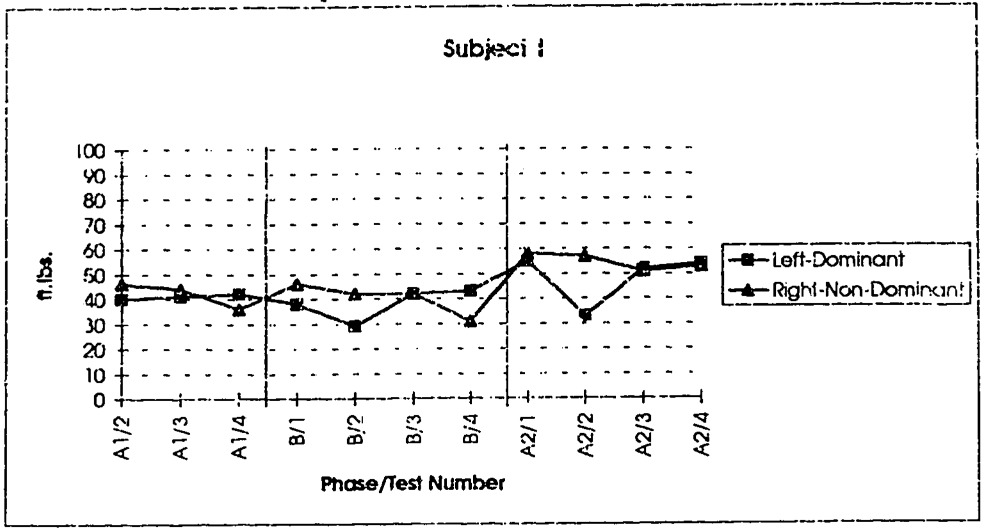
Peak Torque Extension 0.52 rad sec⁻¹

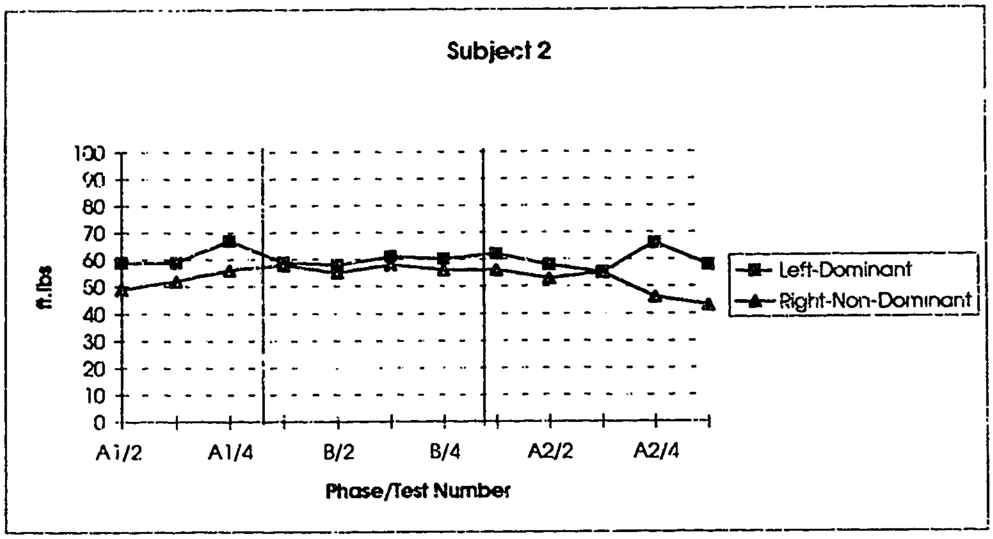


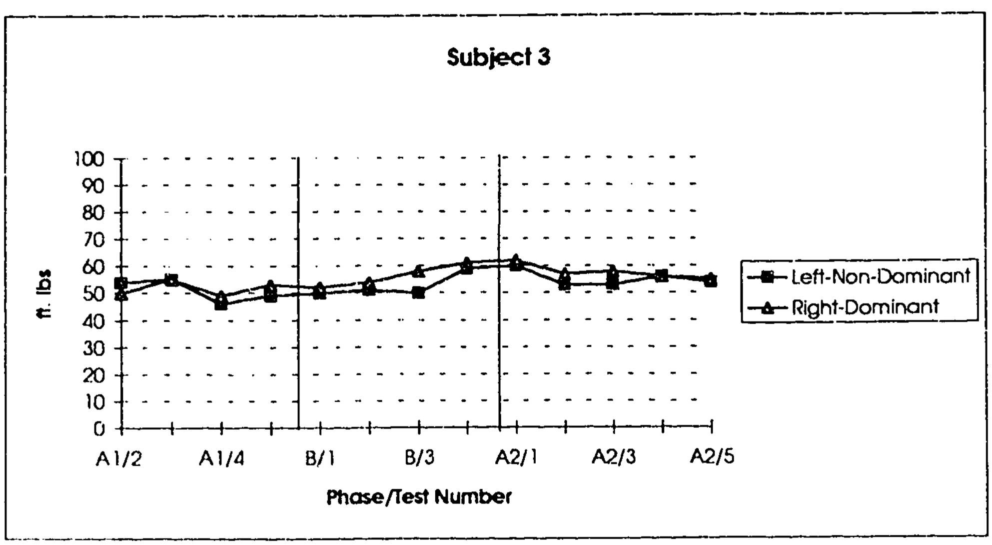


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Peak Torque Flexion 1.05 rad$\cdot$sec^{-1}

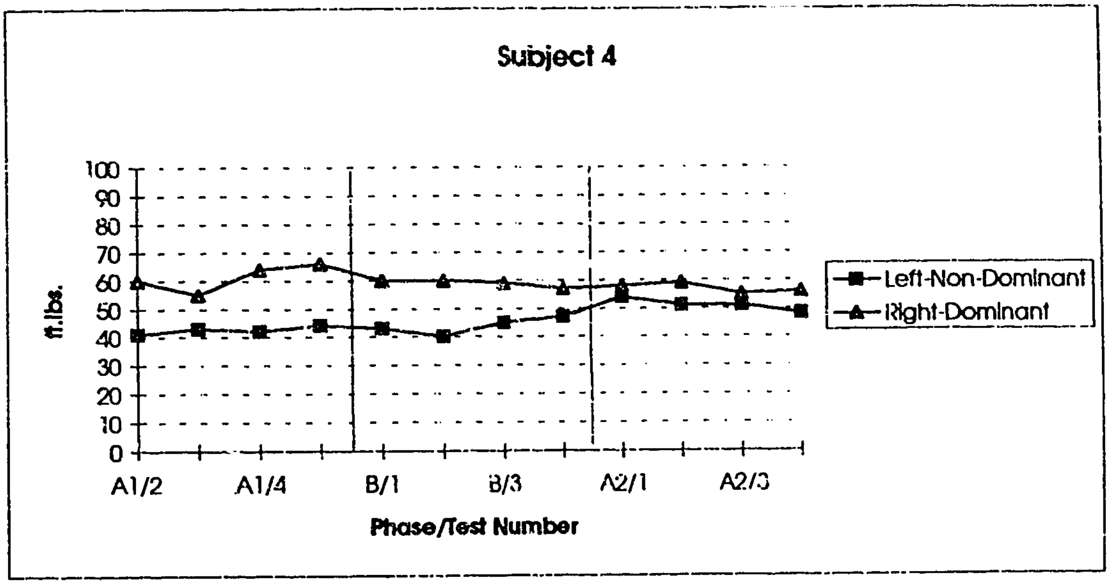


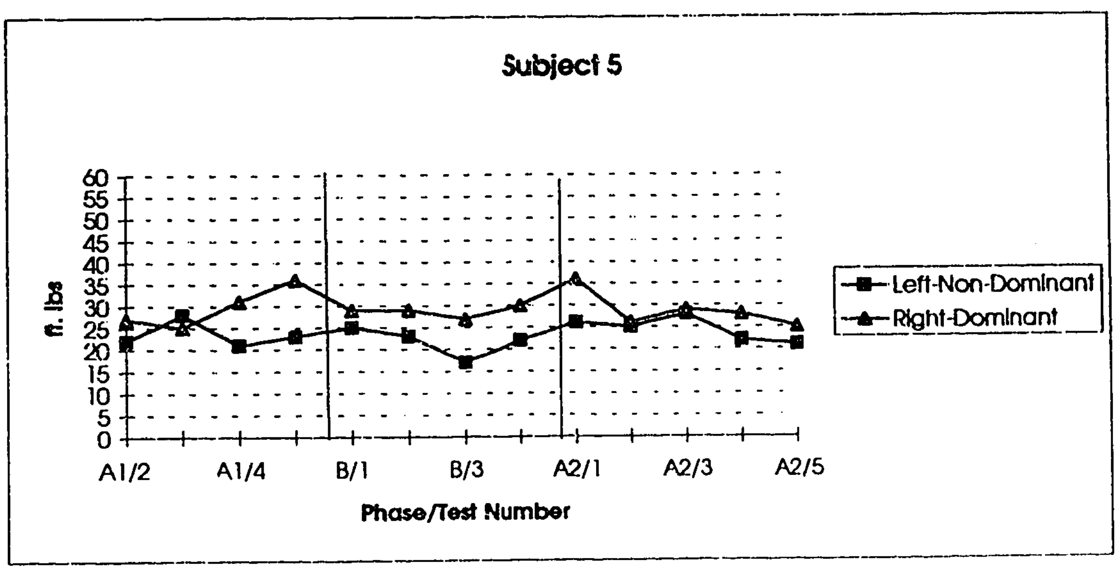




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

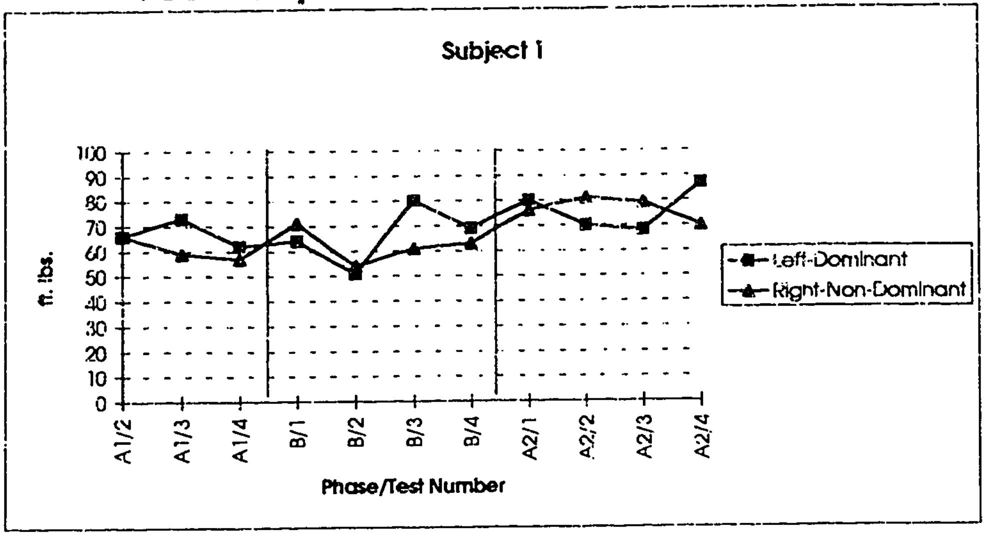
Peak Torque Flexion 1.05 rad·sec^{-1}

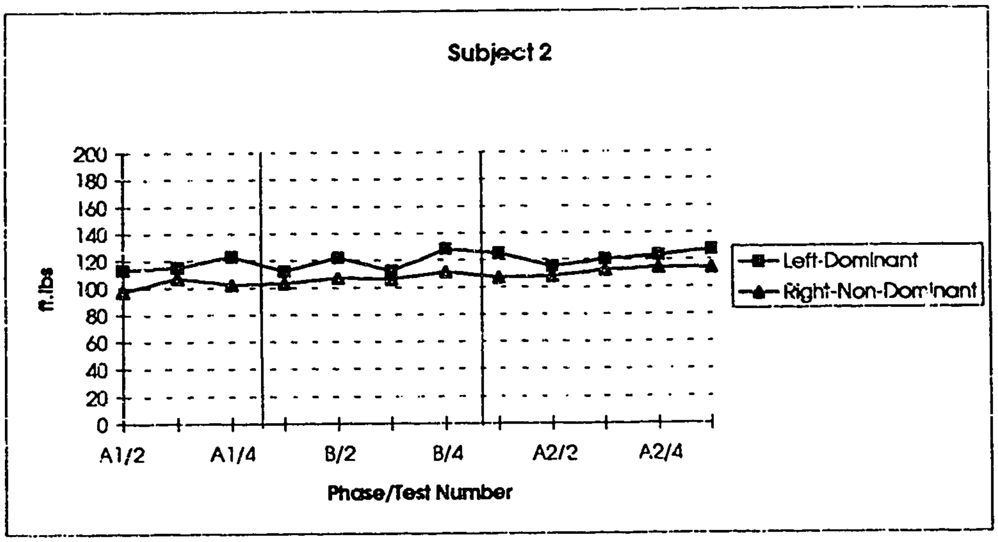


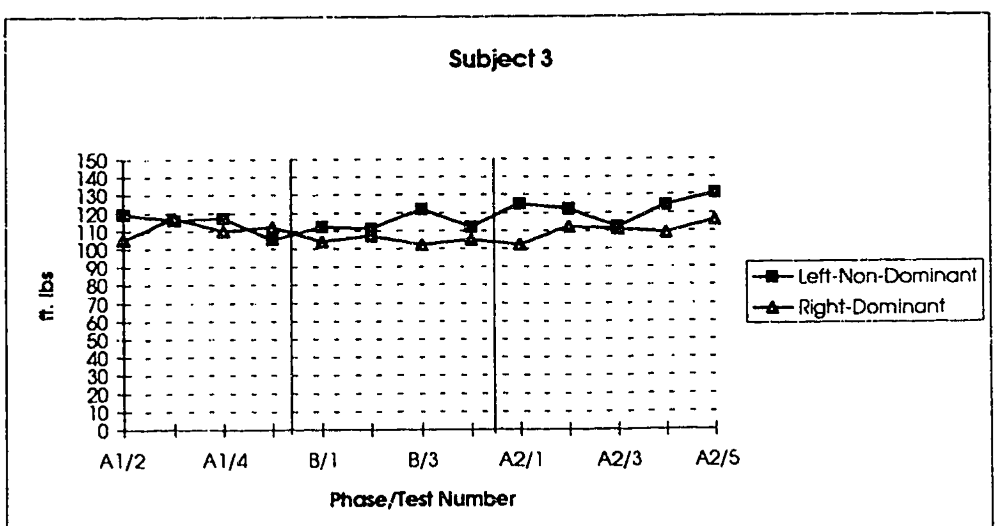


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Peak Torque Extension 1.05 rad·sec^{-1}

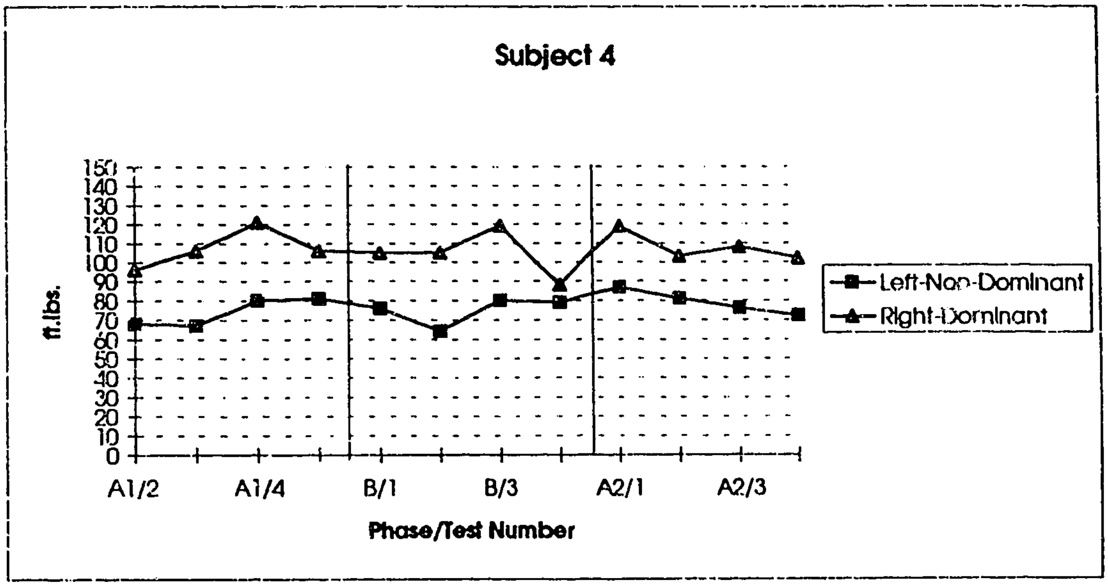


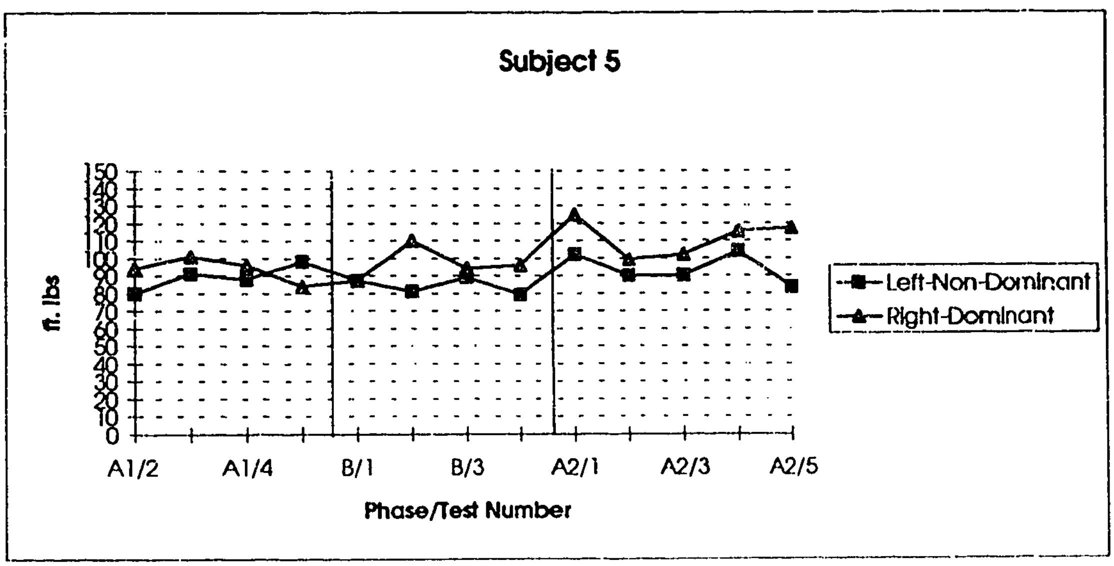




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

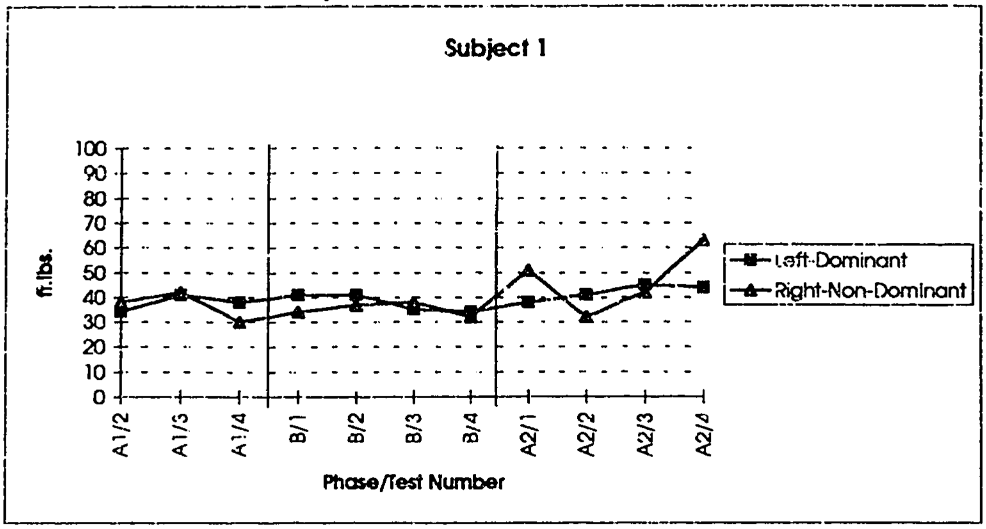
Peak Torque Extension 1.05 rad·sec⁻¹

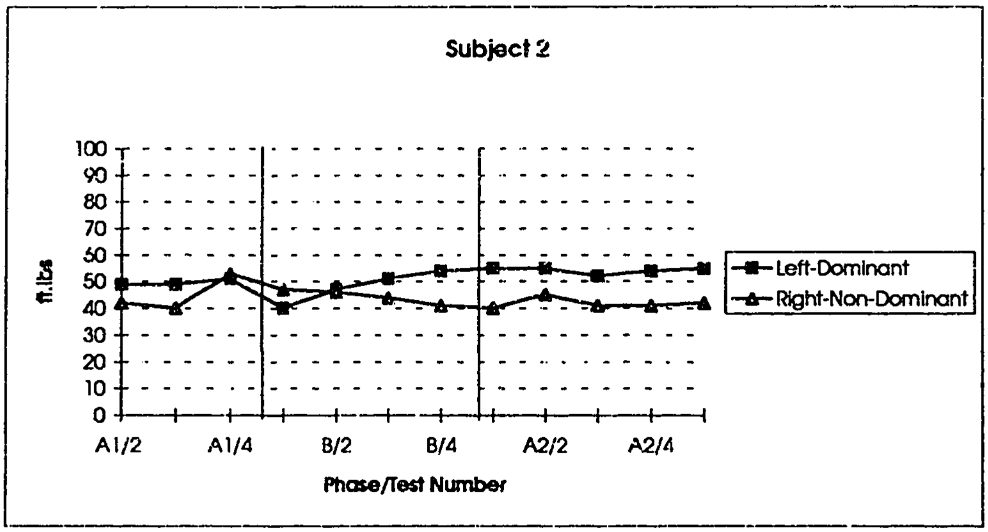


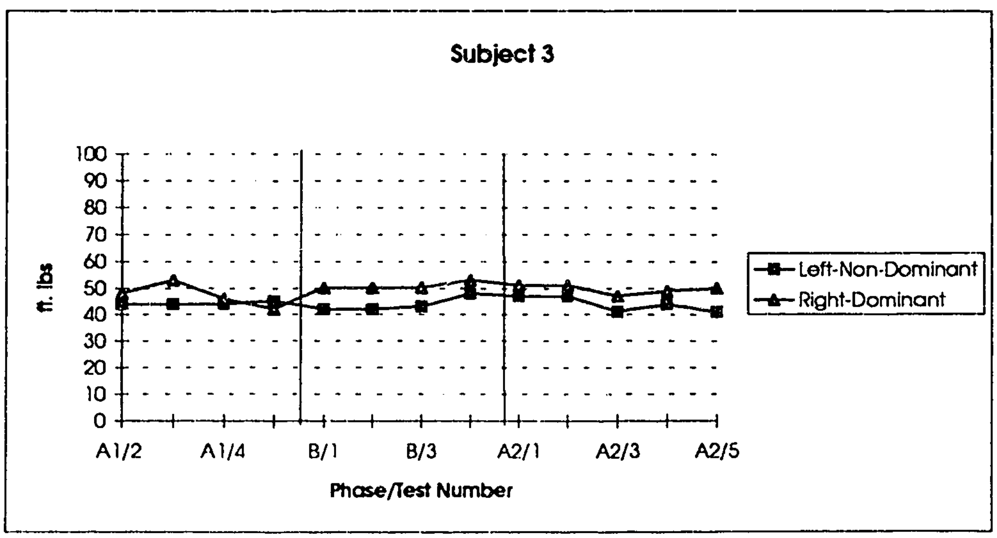


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Peak Torque Flexion 2.09 rad·sec^{-1}

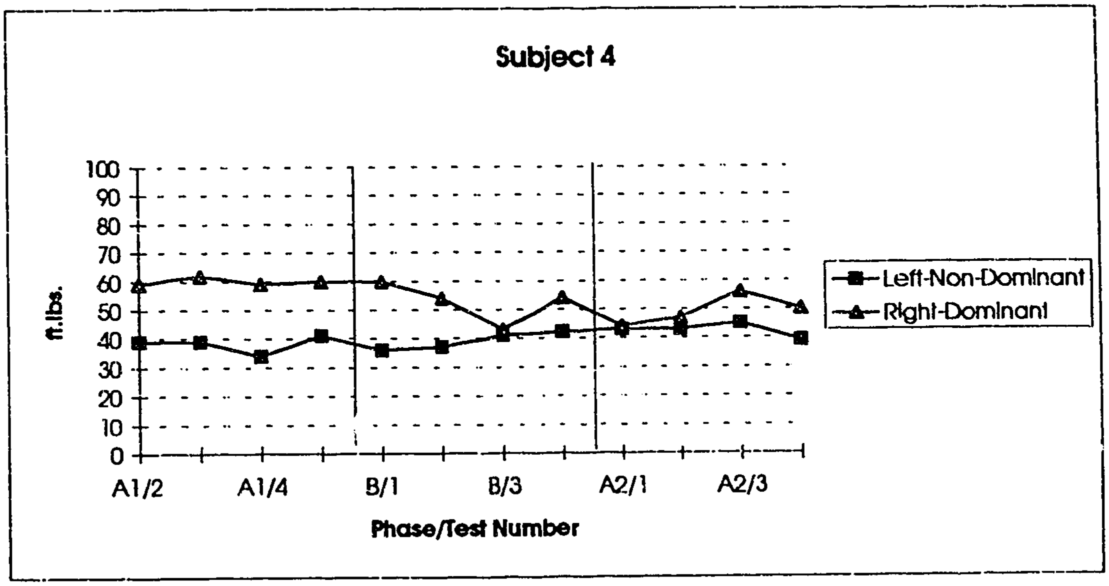


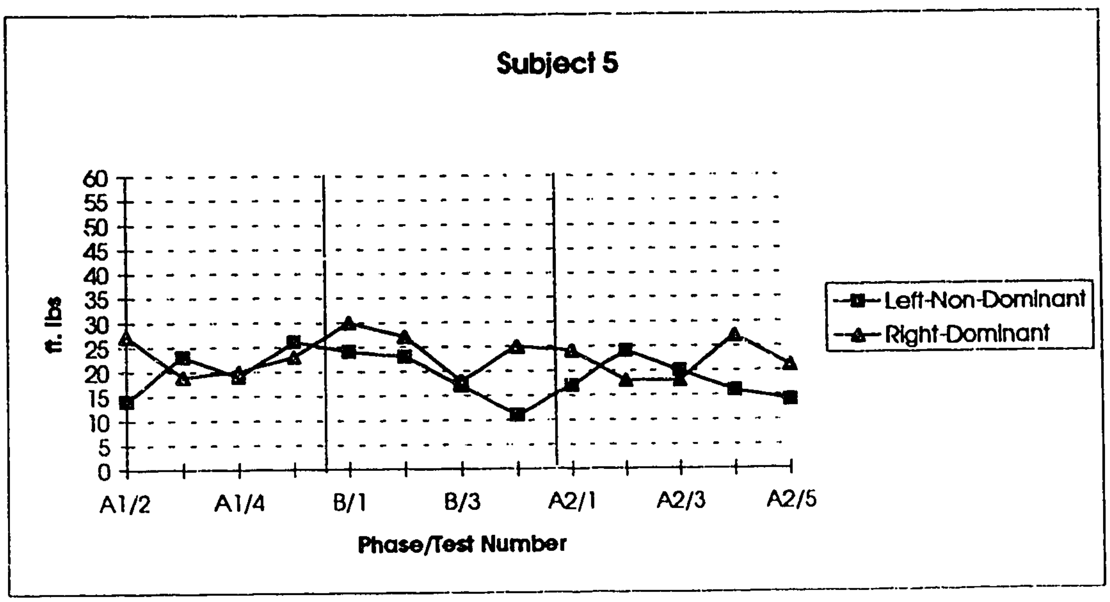




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

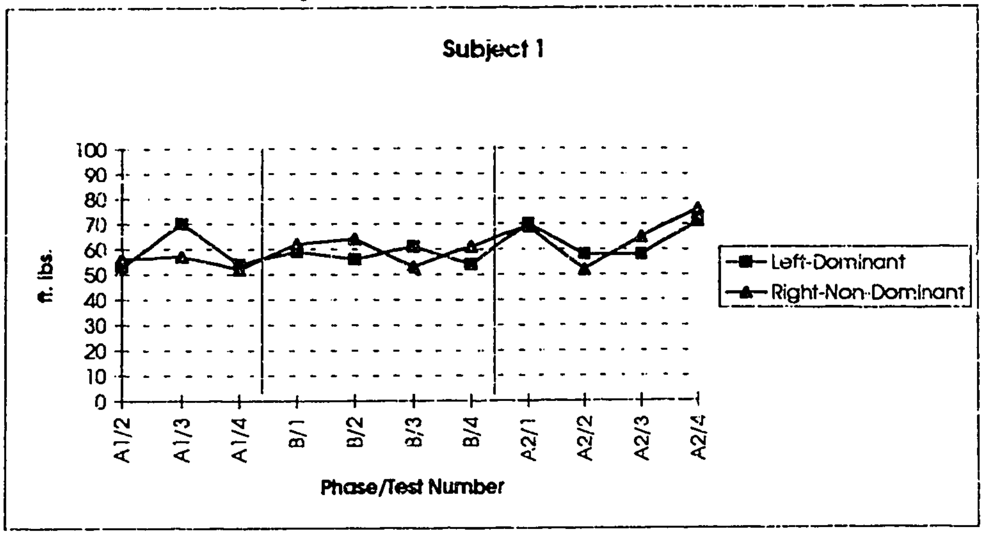
Peak Torque Flexion 2.09 rad·sec^{-1}

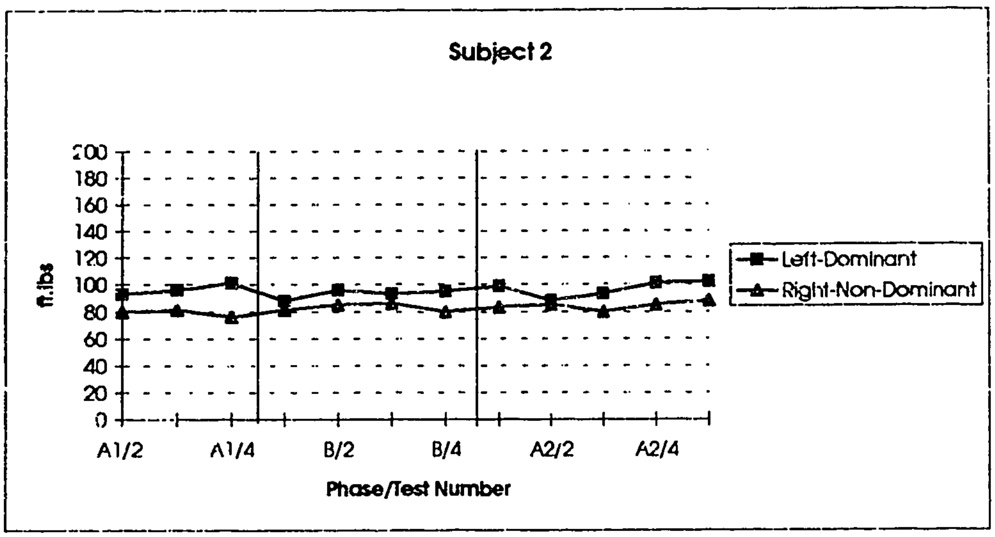


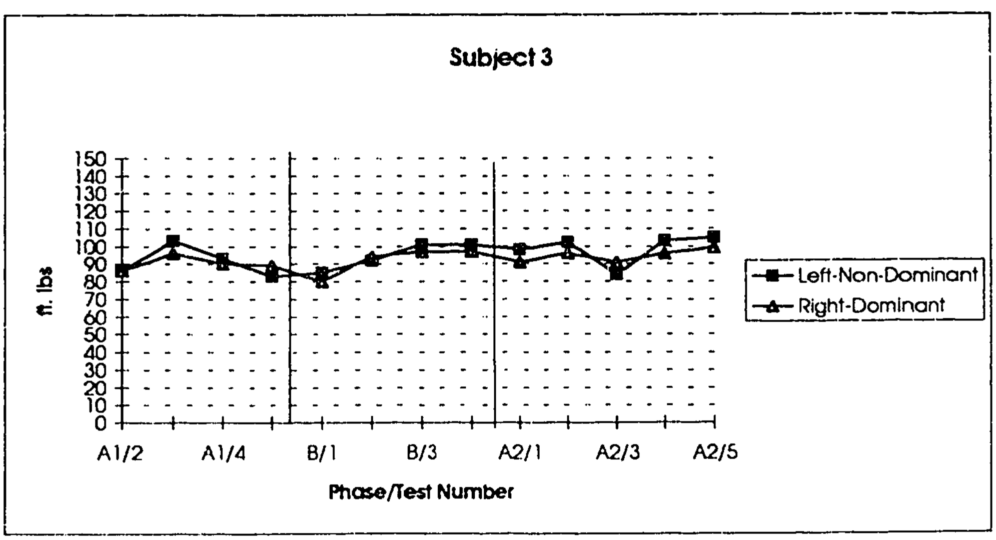


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Peak Torque Extension 2.09 rad·sec⁻¹

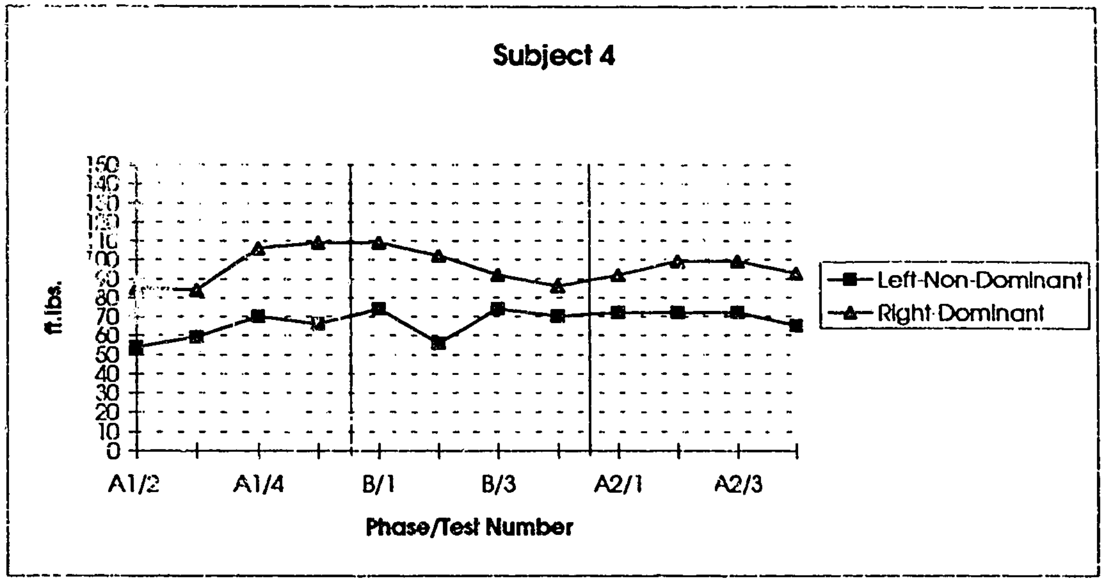


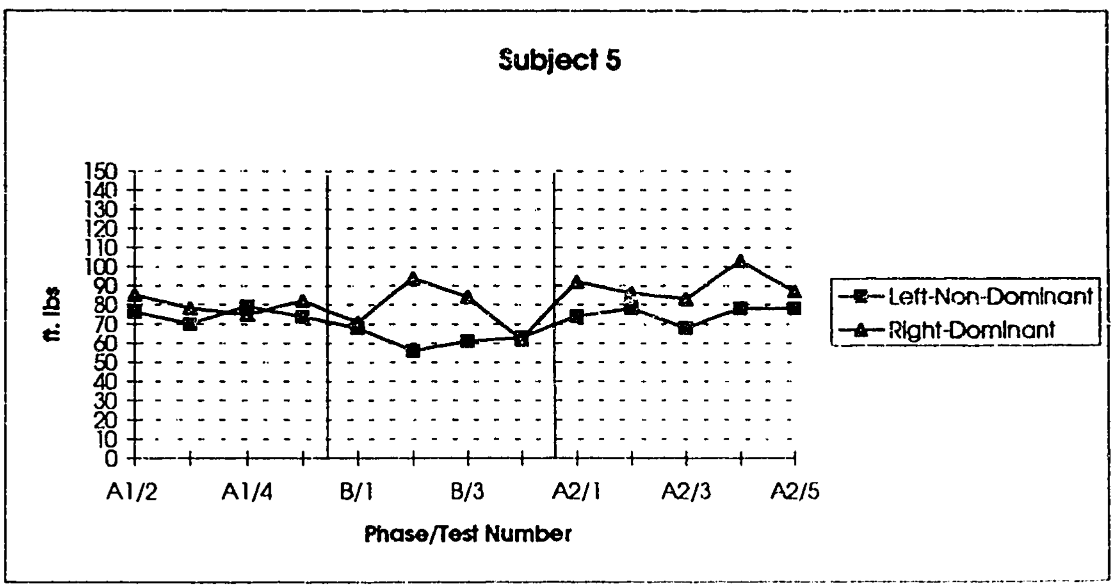




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

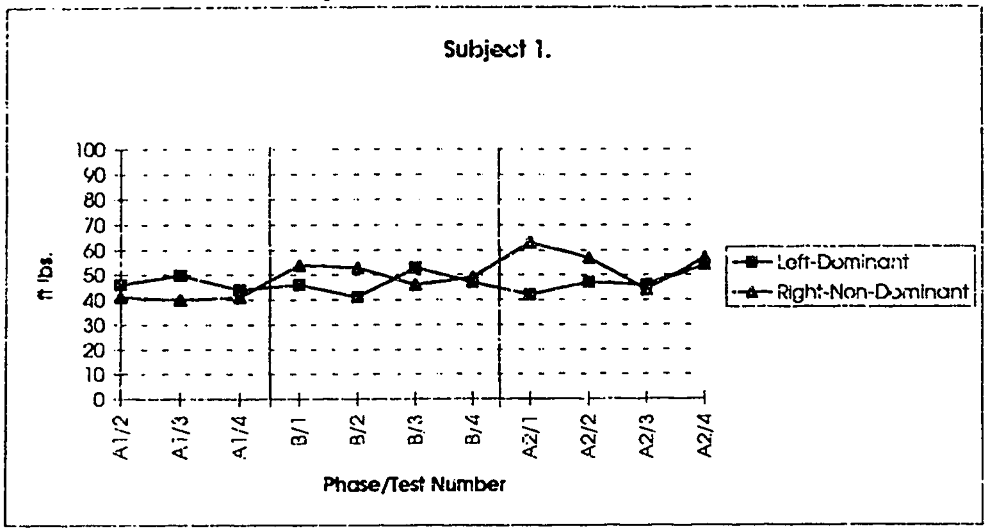
Peak Torque Extension 2.09 $rad \cdot sec^{-1}$

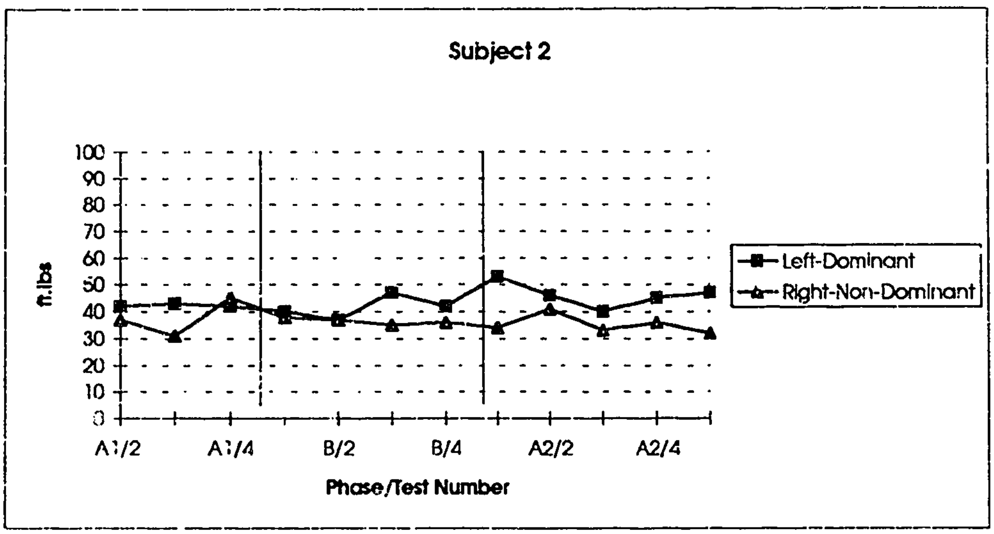


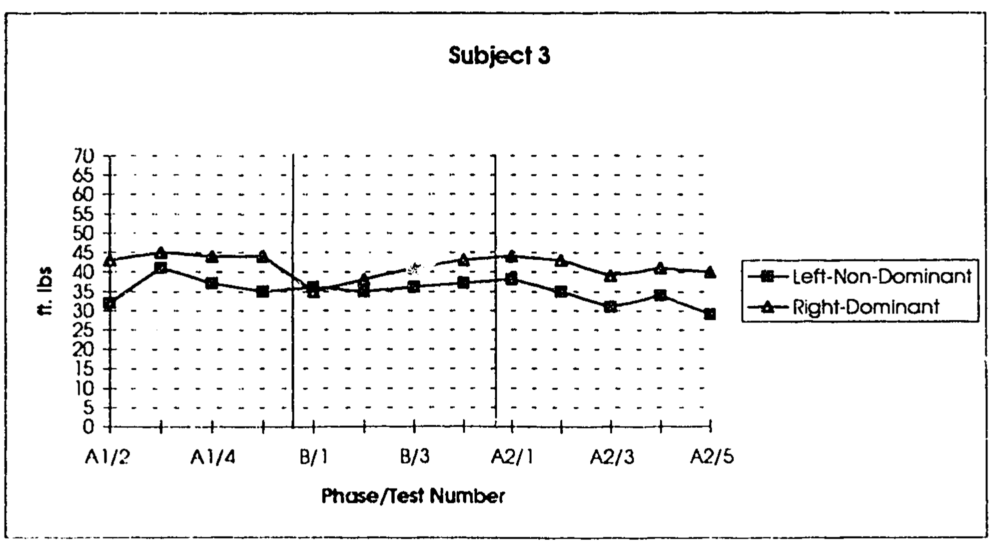


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Peak Torque Flexion 3.14 $rad sec^{-1}$

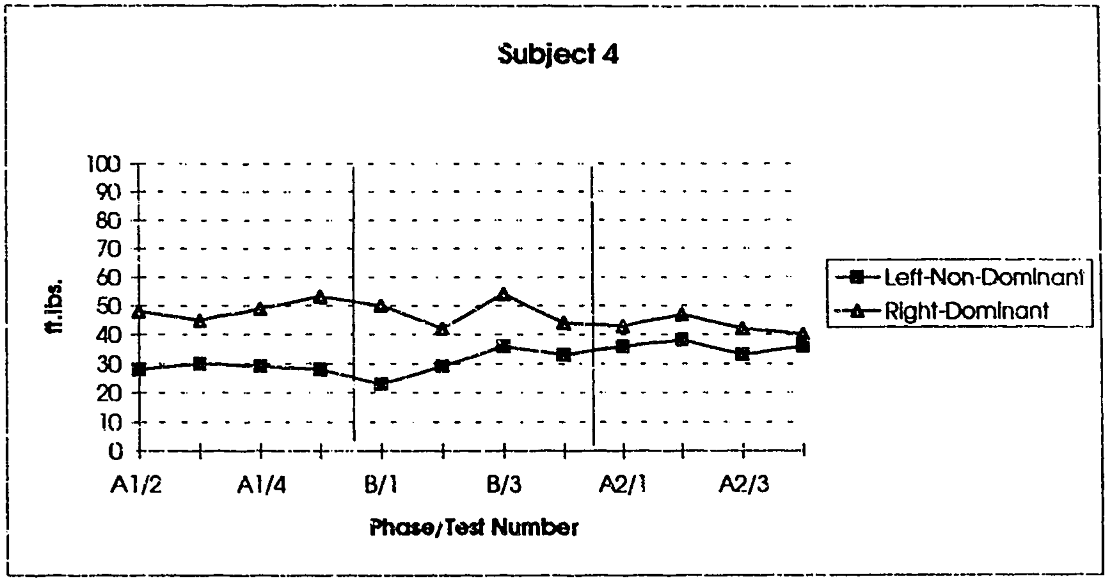


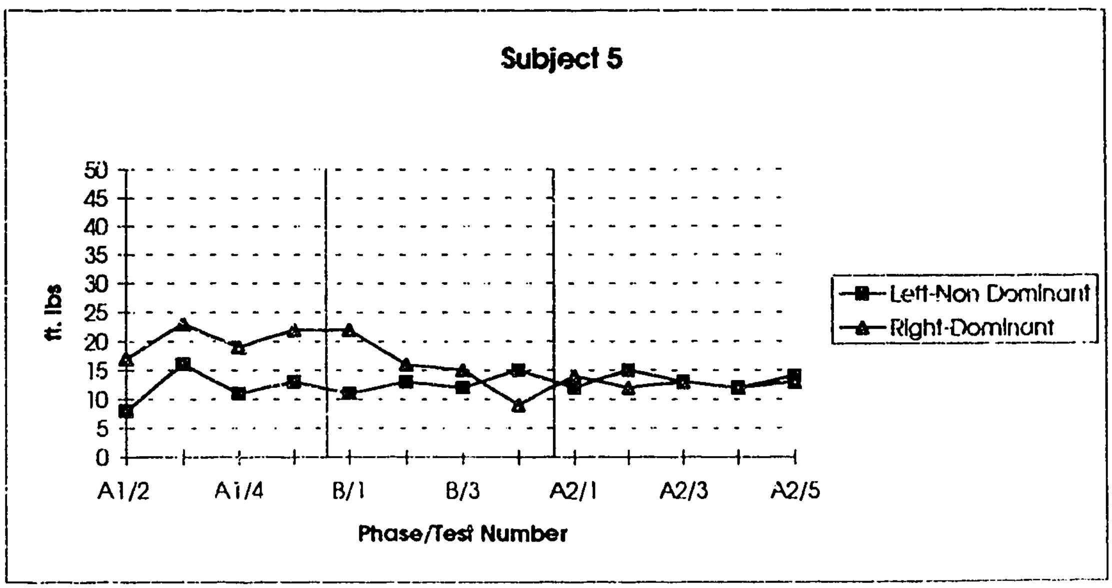




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

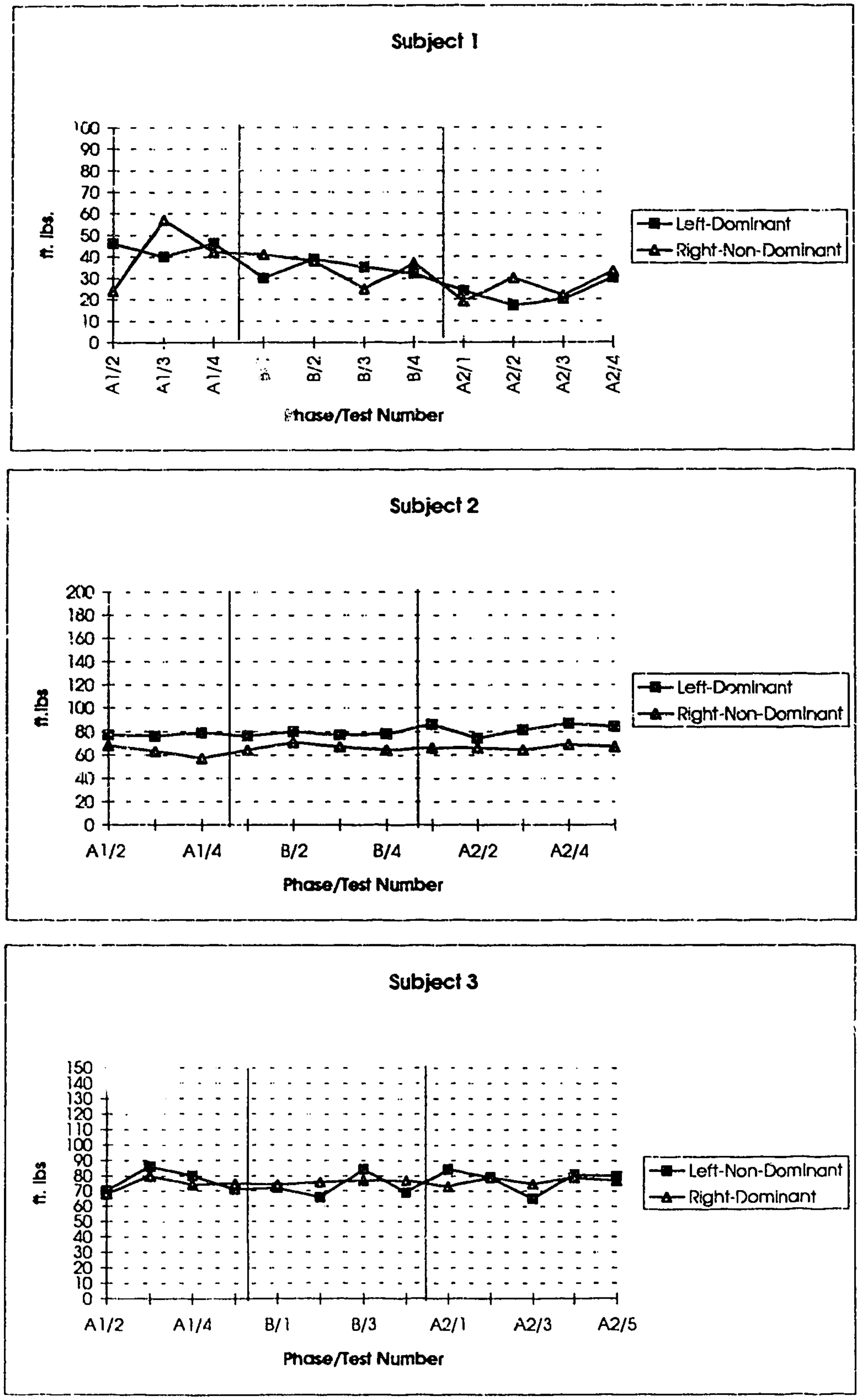
Peak Torque Flexion 3.14 rad·sec^{-1}





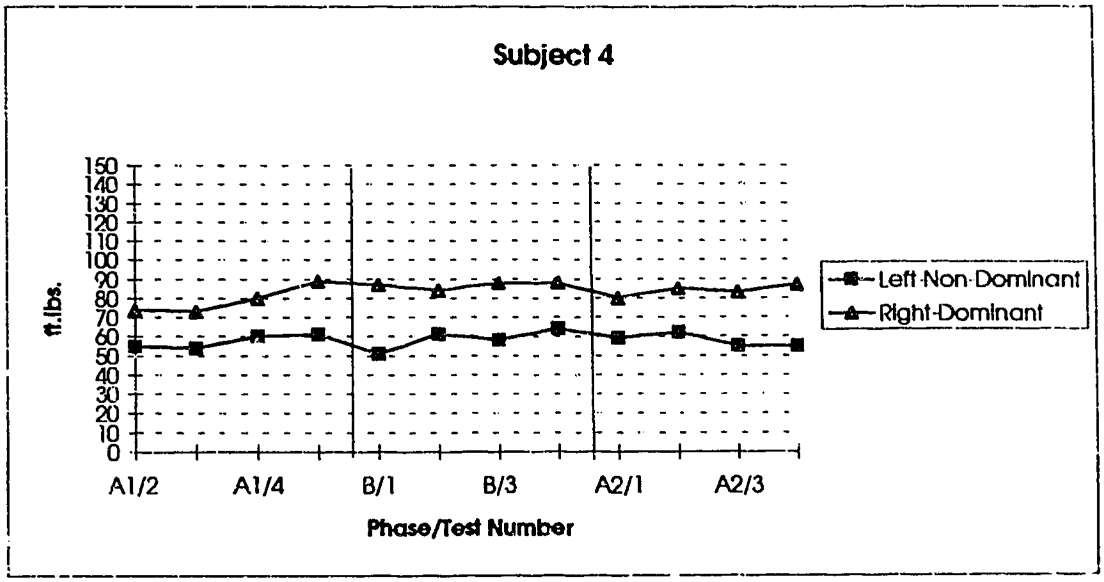
A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

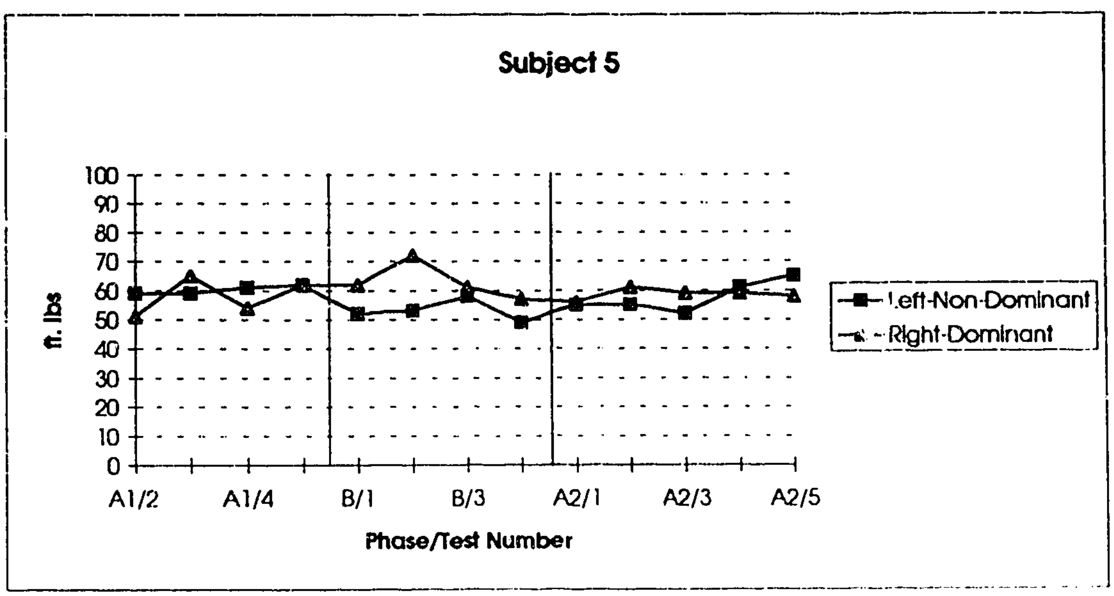
Peak Torque Extension 3.14 rad sec⁻¹



A1 - Baseline Phase   B - Intervention Phase   A2 - Withdrawal Phase

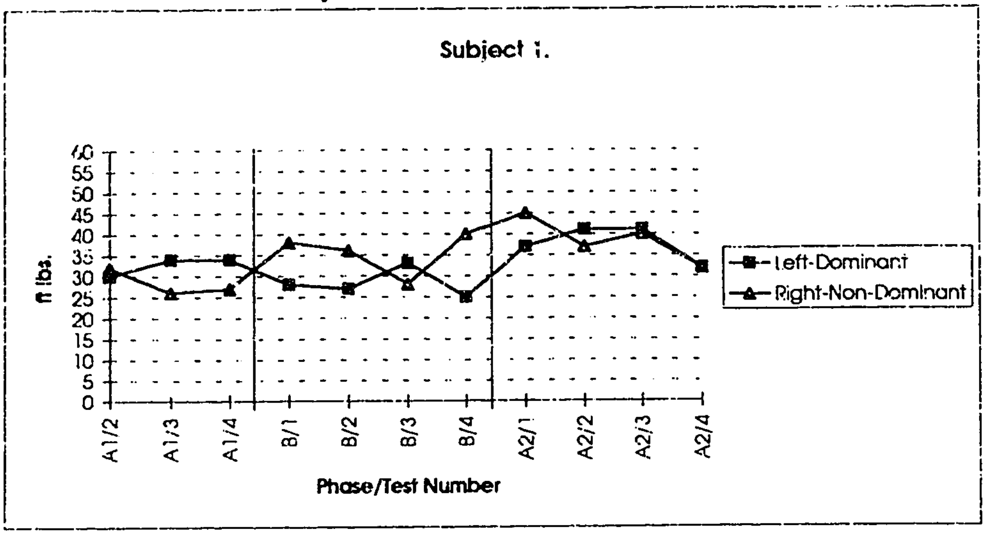
Peak Torque Extension 3.14 rad·sec⁻¹

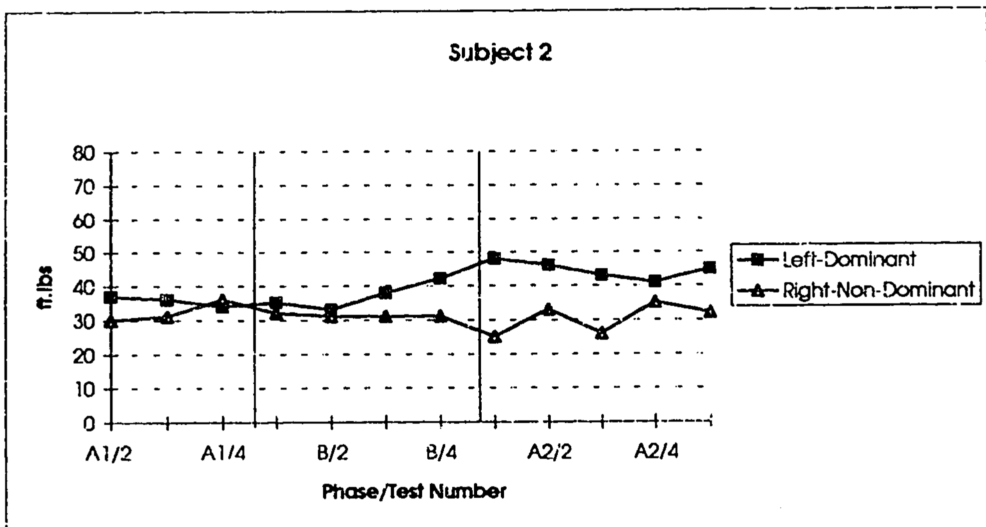


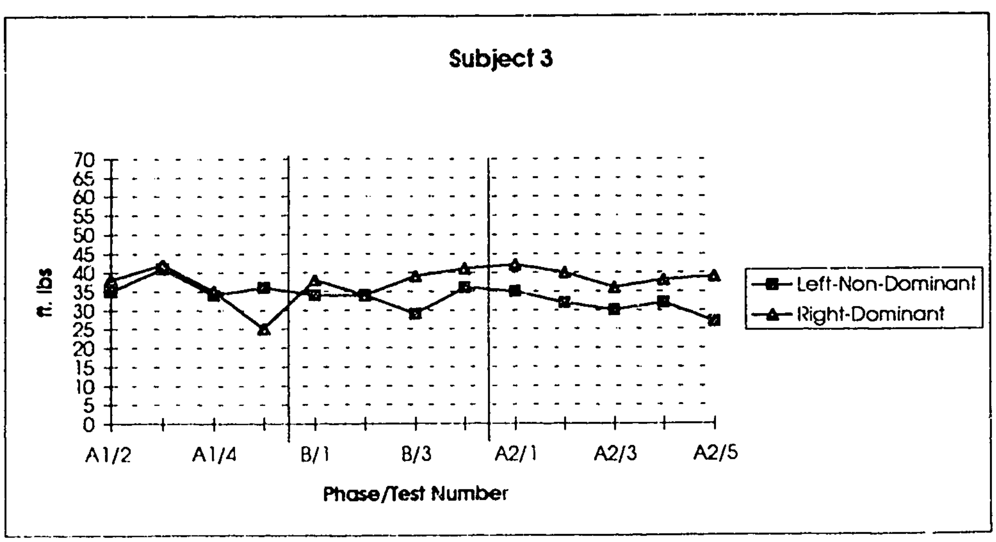


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Peak Torque Flexion 4.19 rad·sec^{-1}

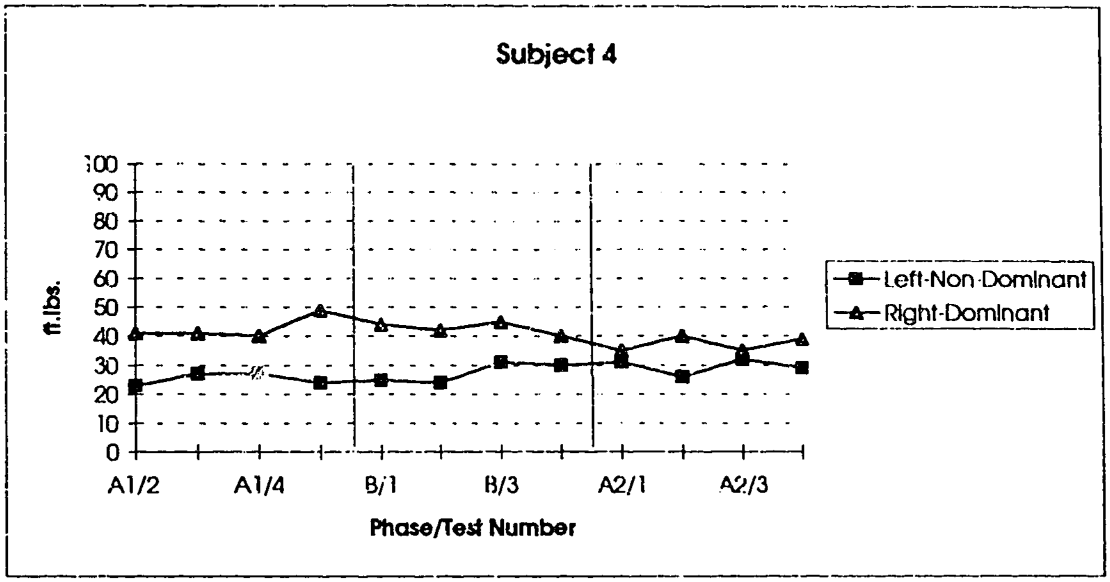


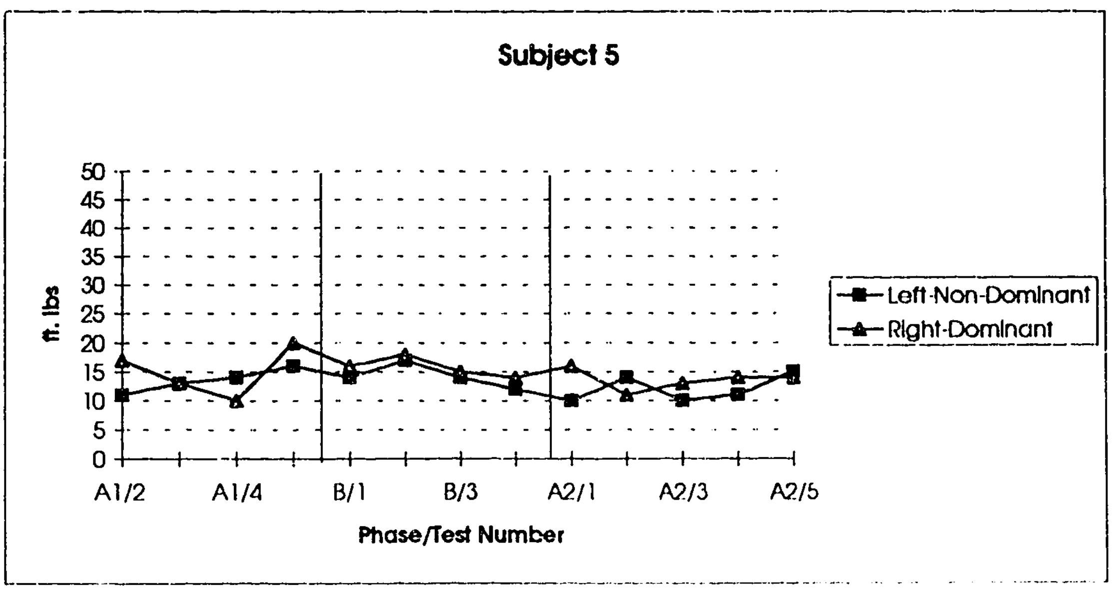




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

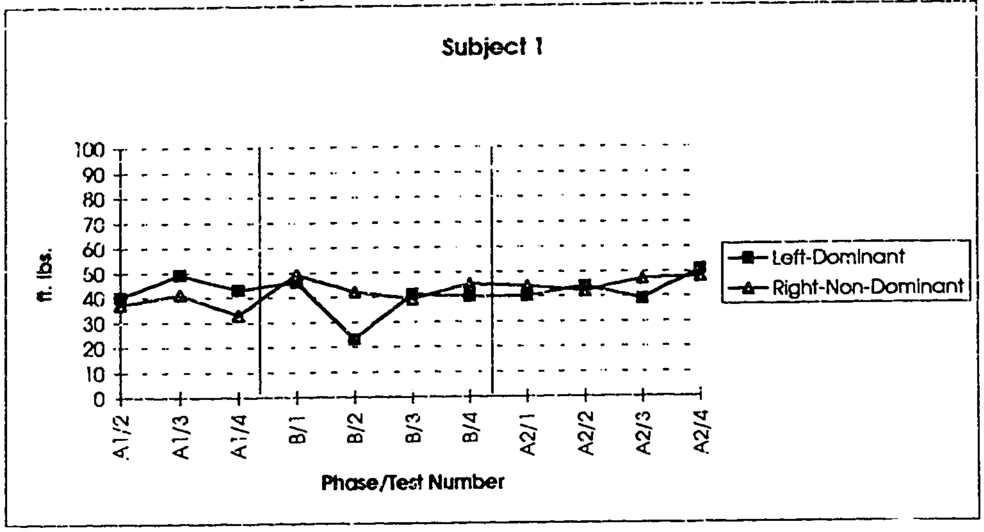
Peak Torque Flexion 4.19 rad·sec⁻¹

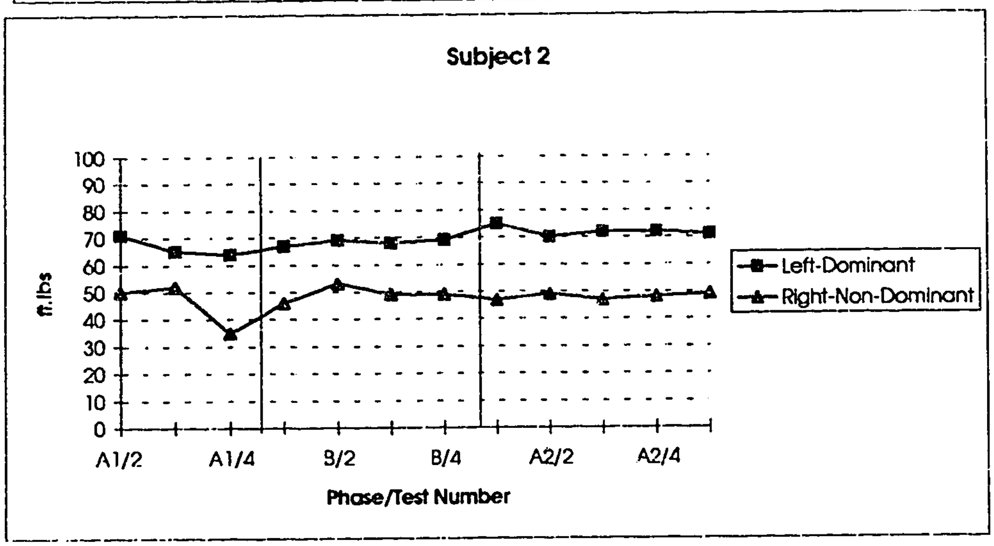


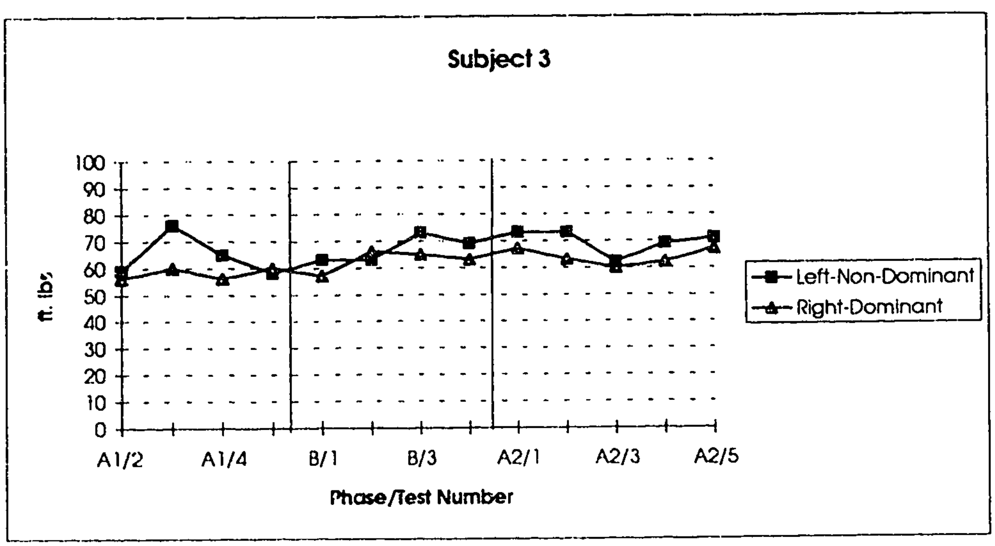


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Peak Torque Extension 4.19 rad sec[-1]

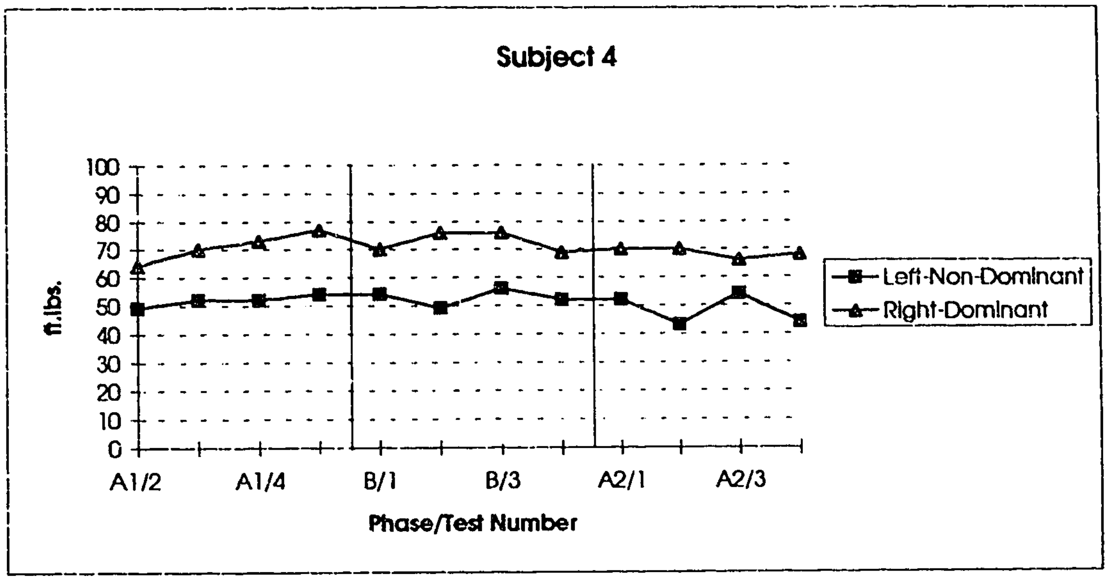


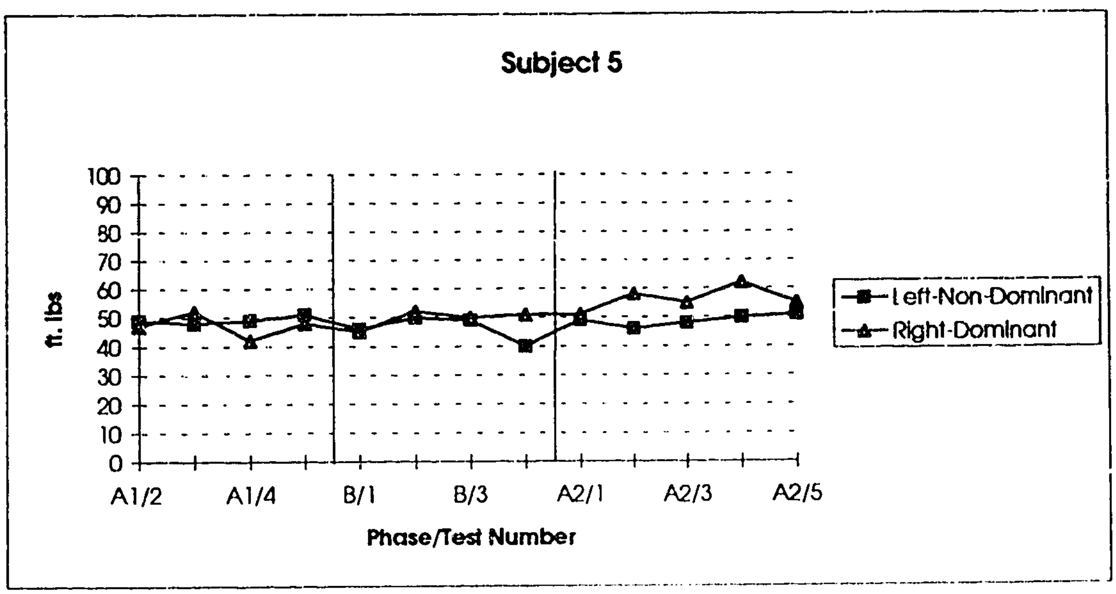




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

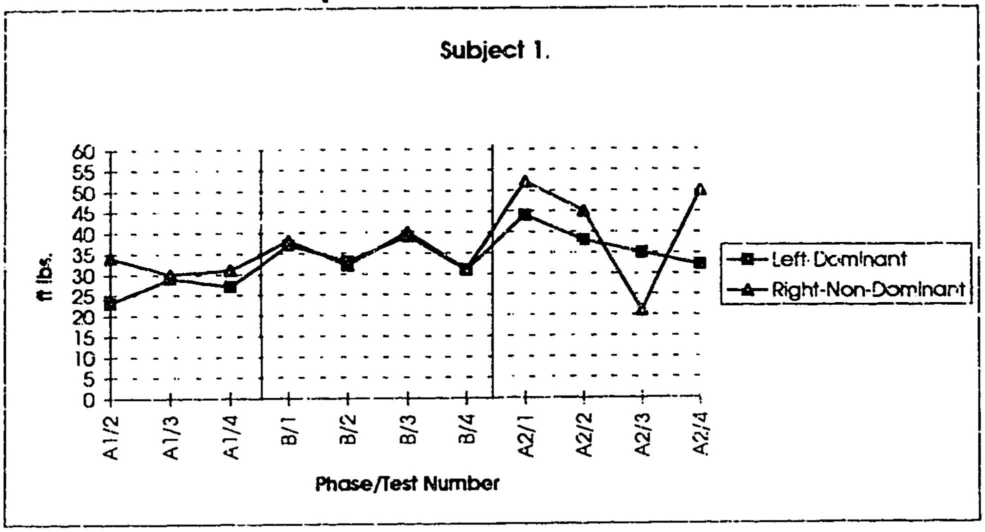
Peak Torque Extension 4.19 rad·sec⁻¹

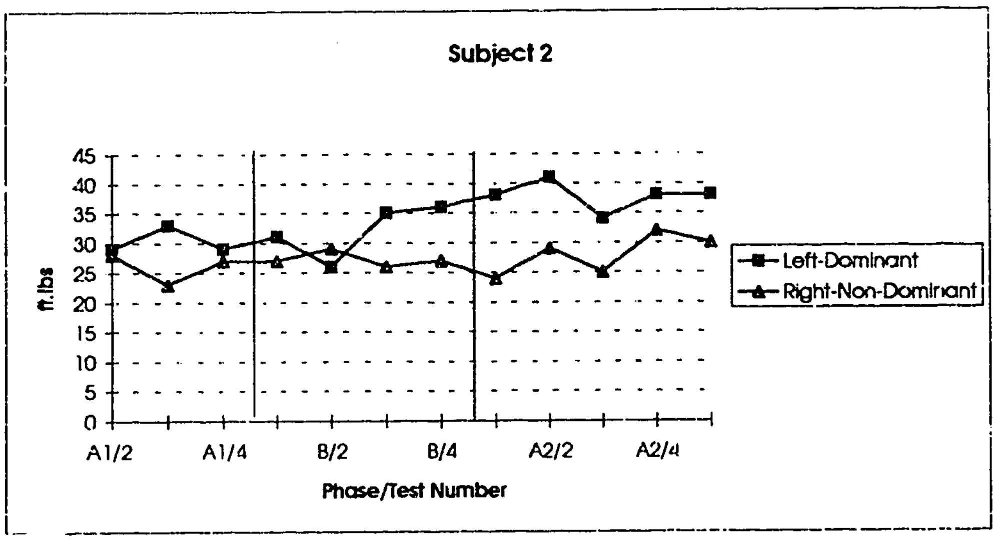


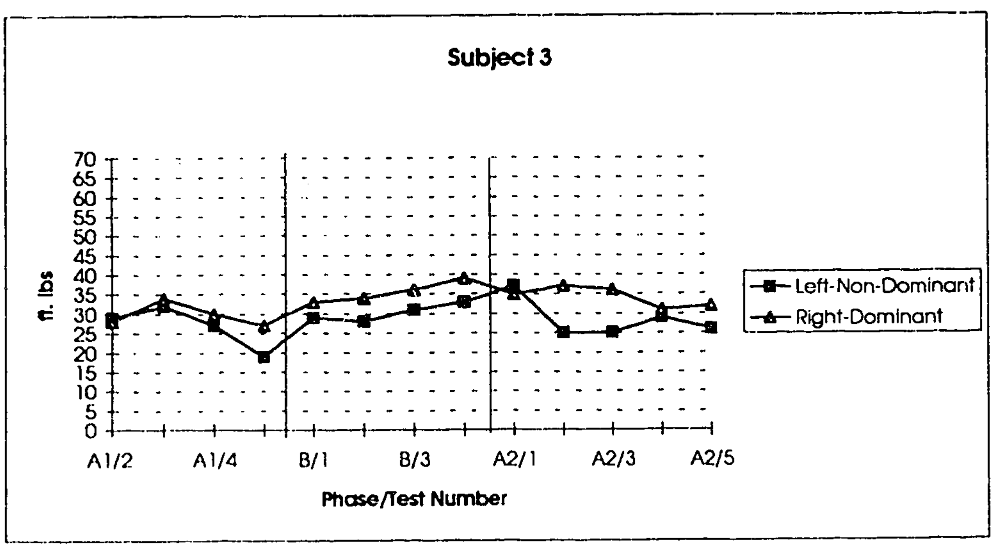


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Peak Torque Flexion 5.24 radsec^{-1}

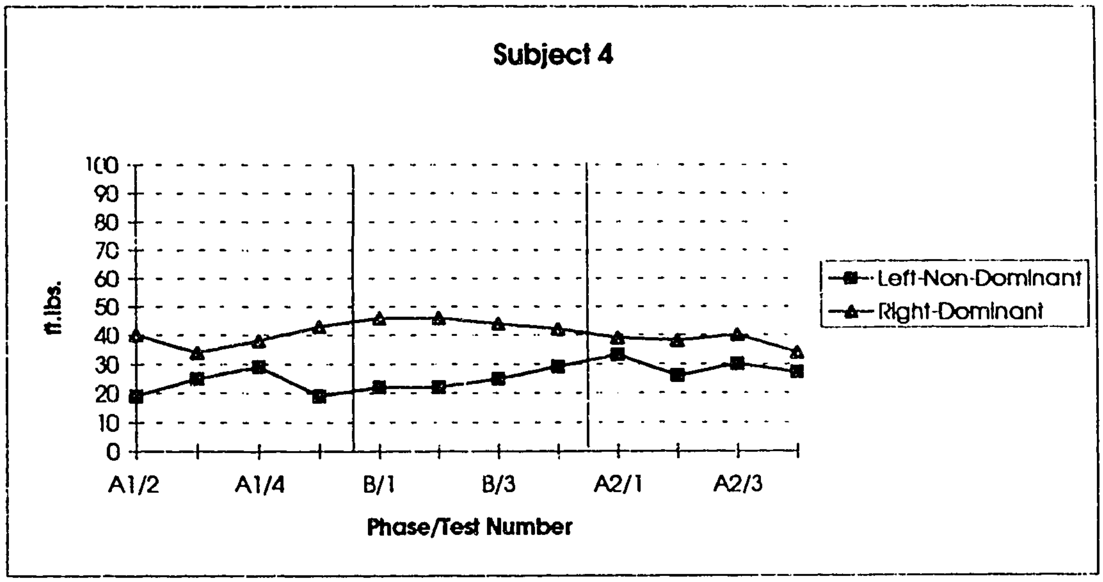


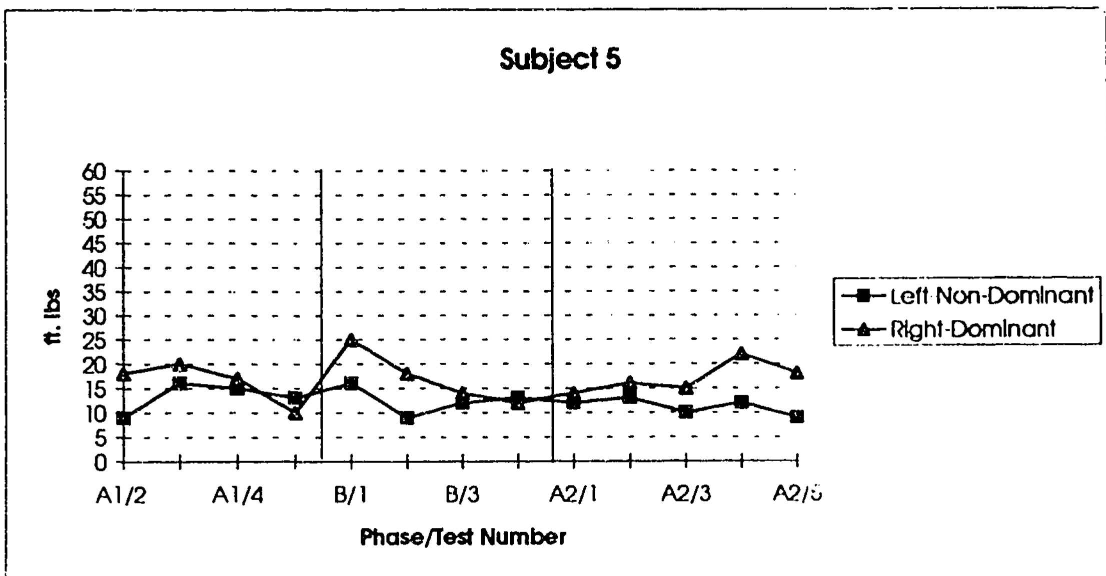




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

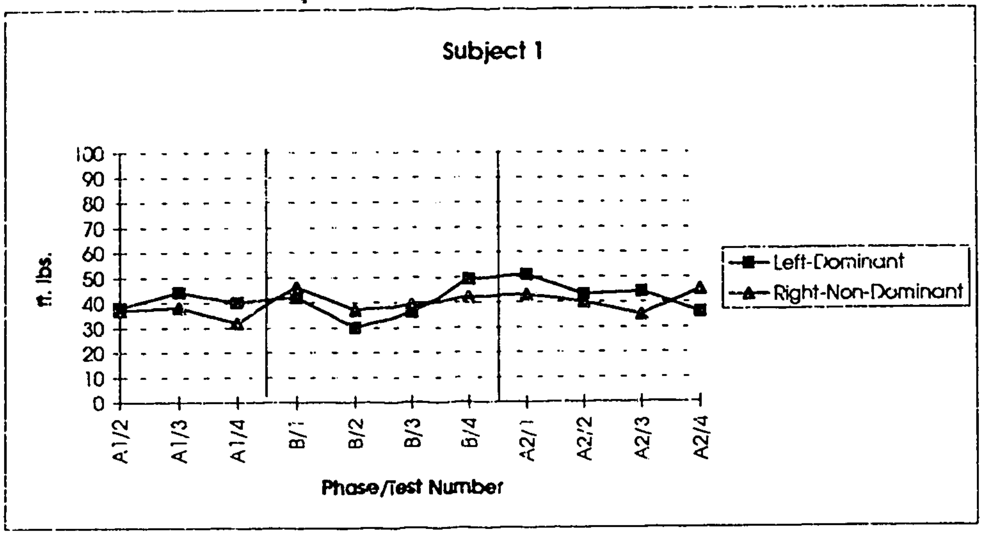
Peak Torque Flexion 5.24 rad/sec

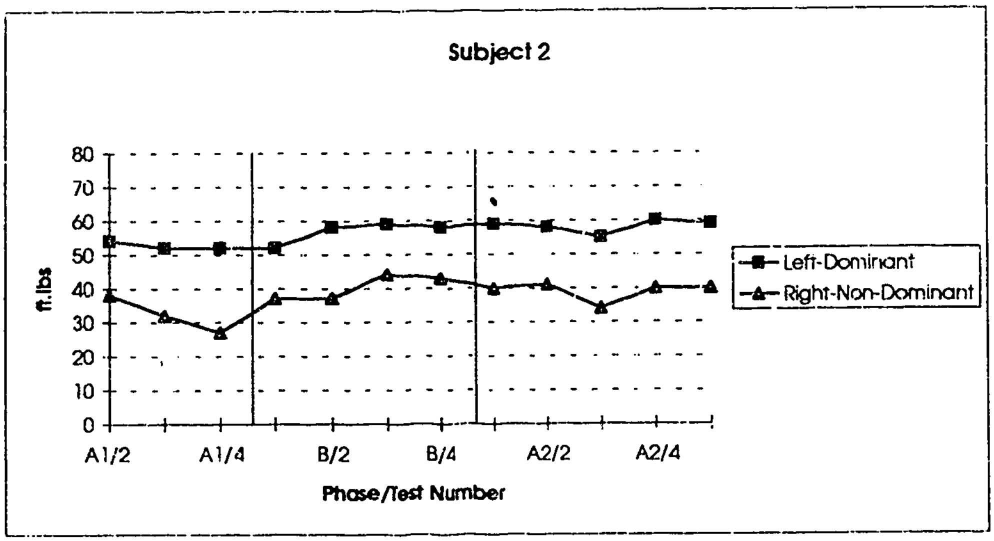


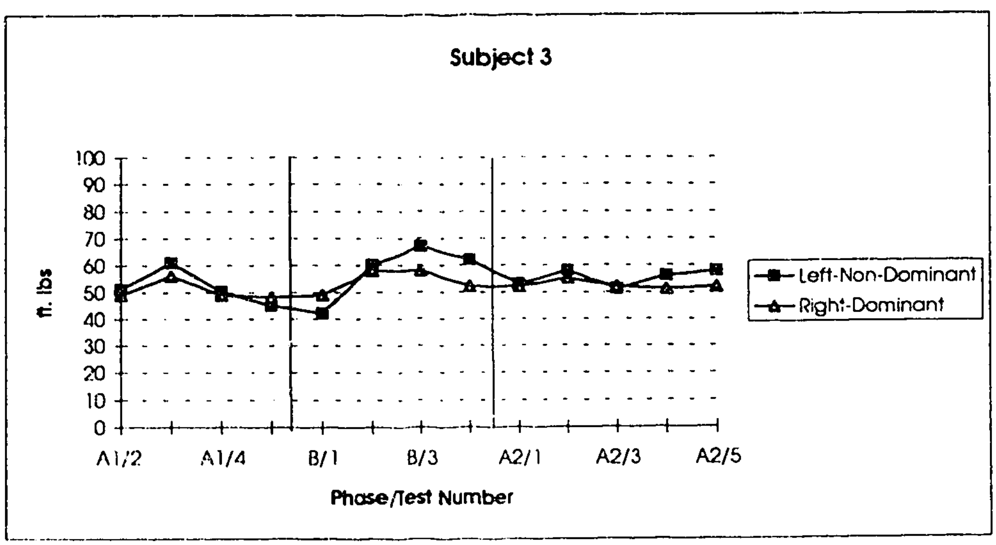


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Peak Torque Extension 5.24 rad·sec^{-1}

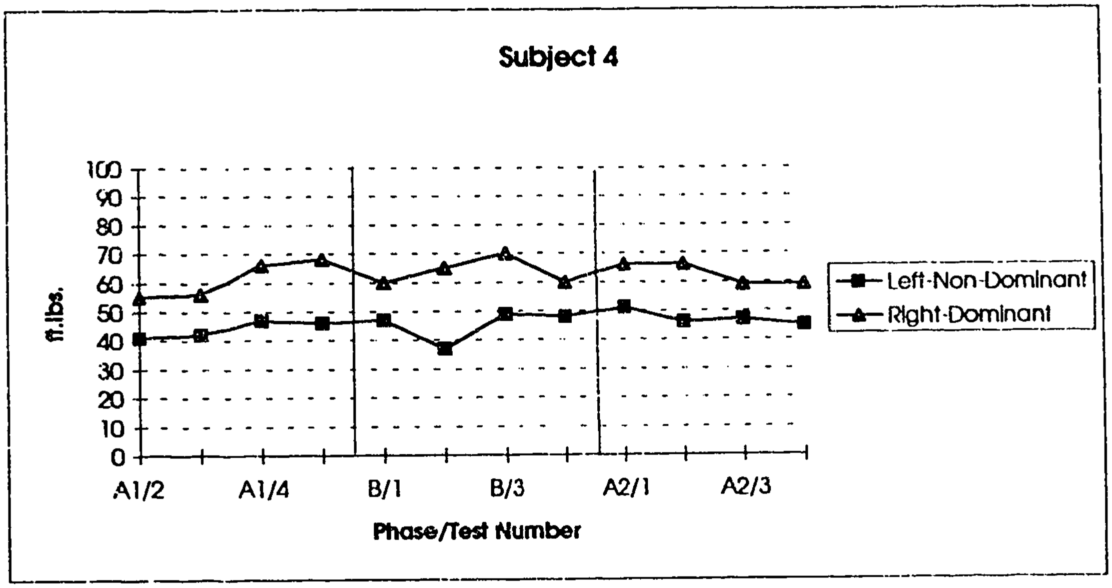


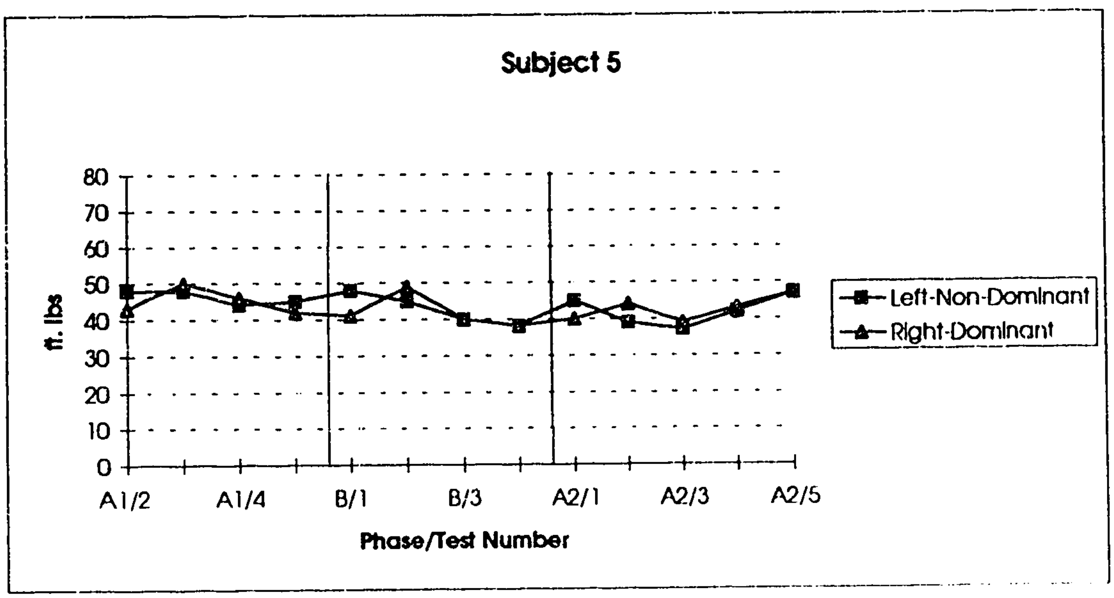




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

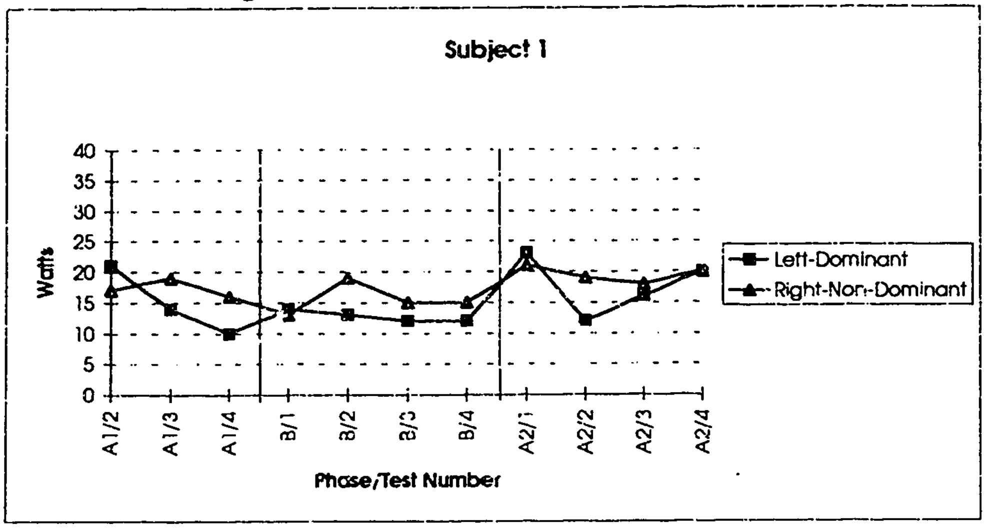
Peak Torque Extension 5.24 rad·sec⁻¹

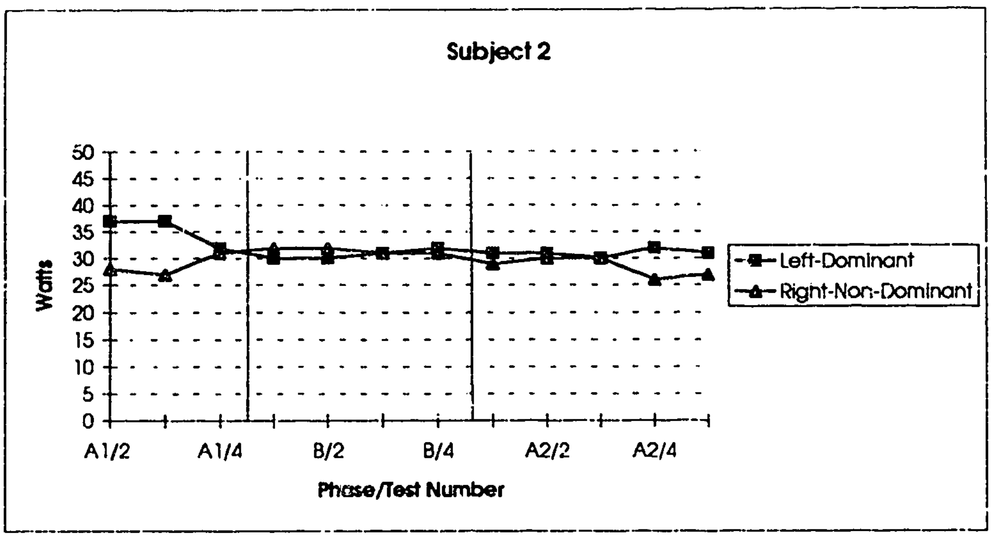


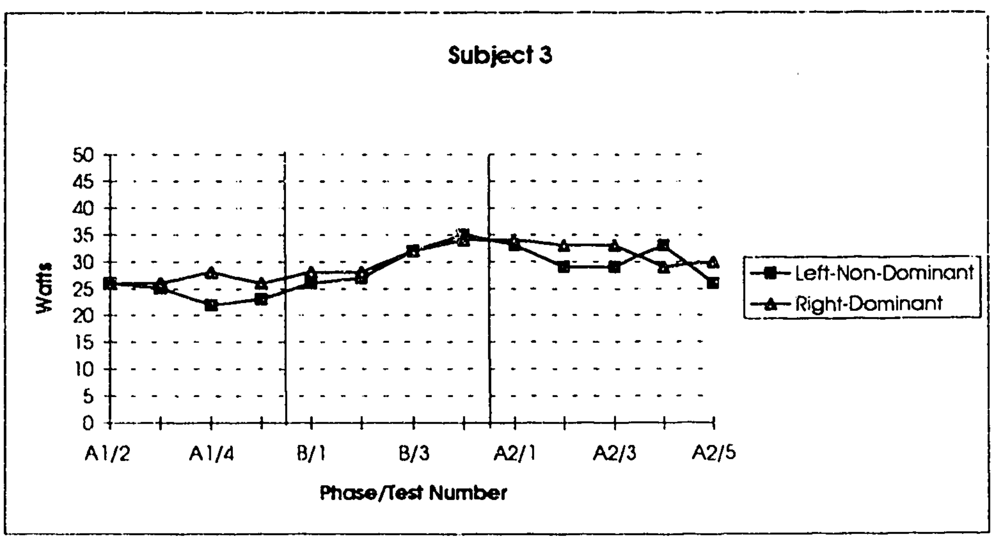


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Average Power Flexion 0.52 rad·sec^{-1}

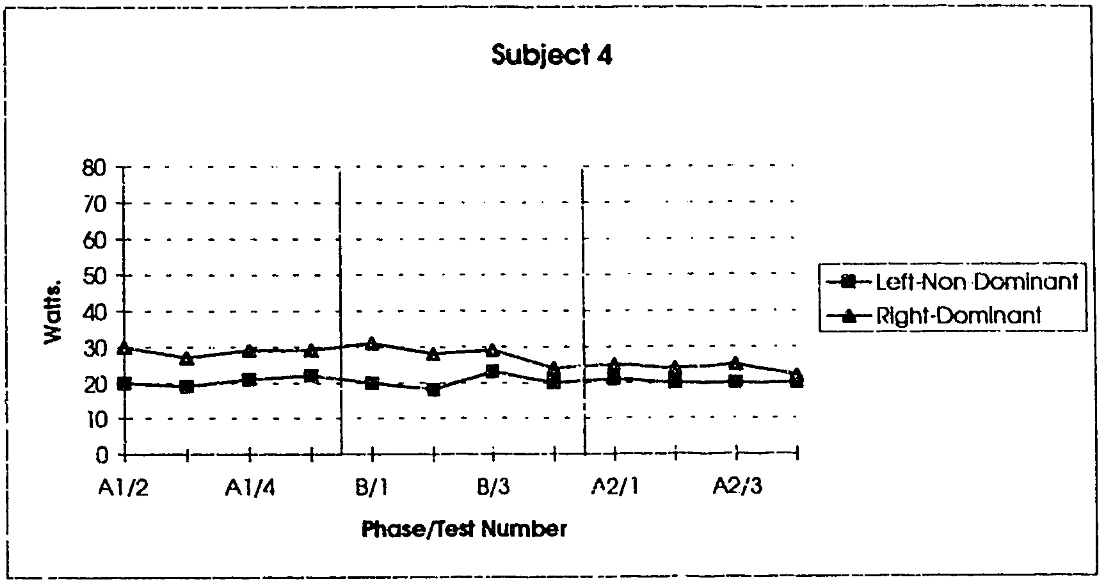


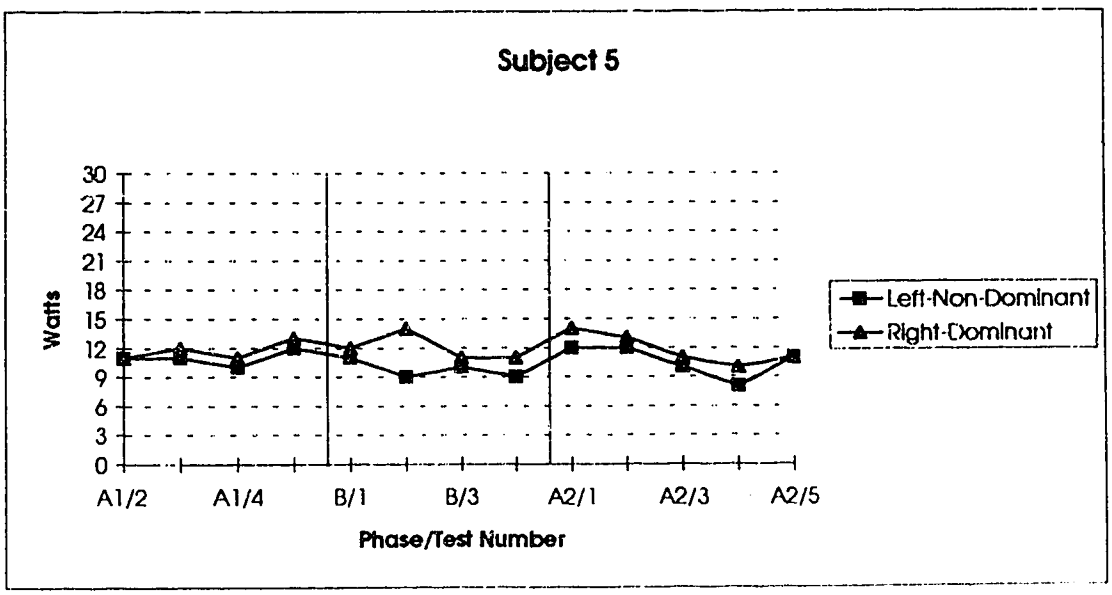




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

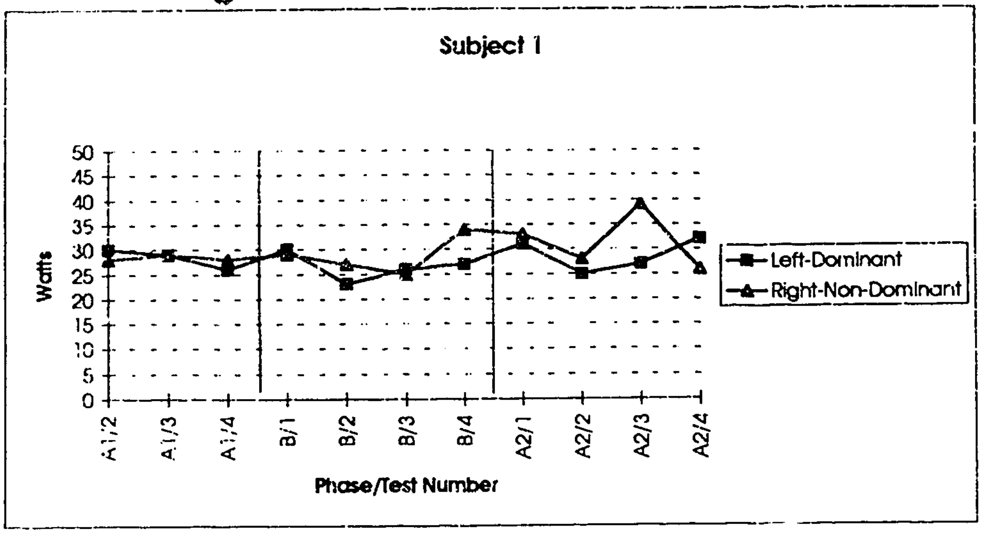
Average Power Flexion 0.52 rad·sec^{-1}

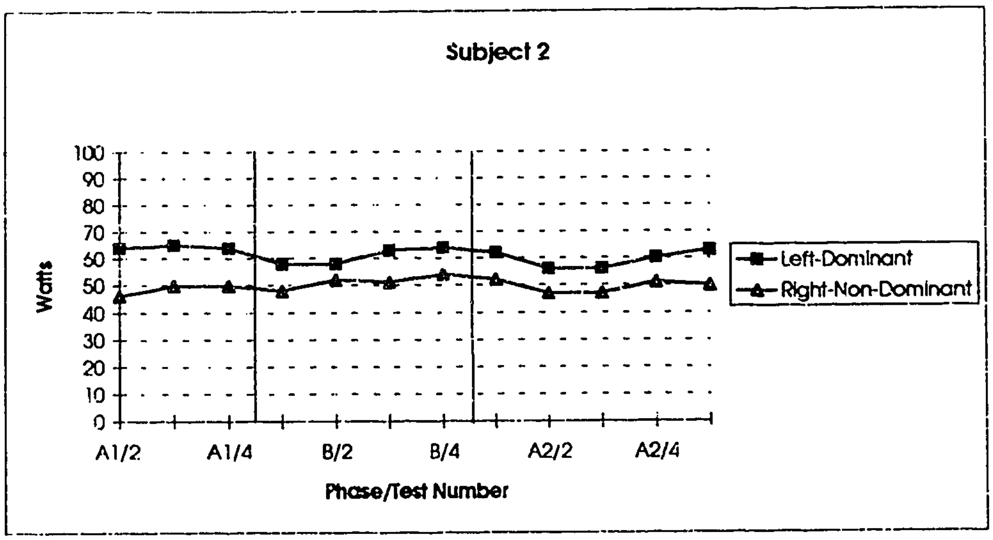


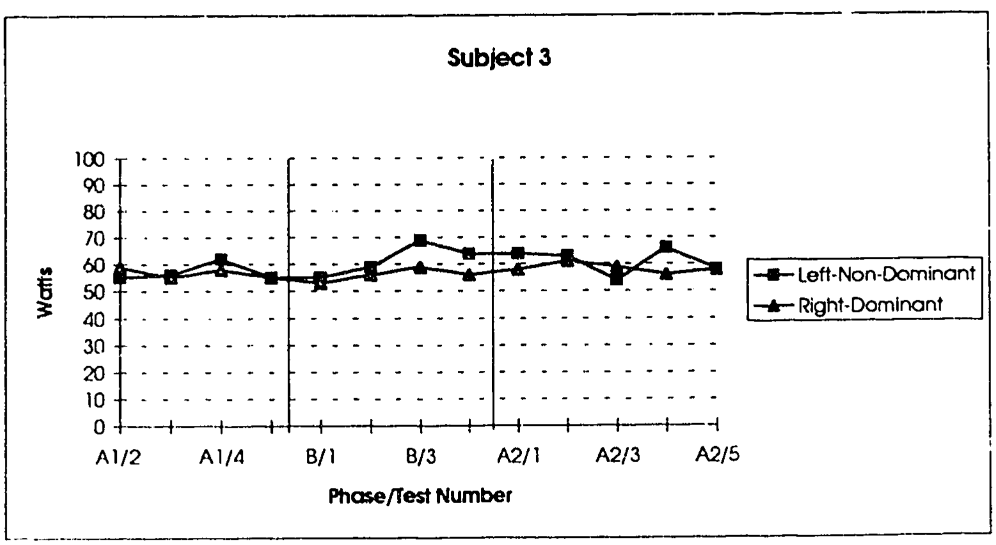


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Average Power Extension 0.52 rad·sec^{-1}

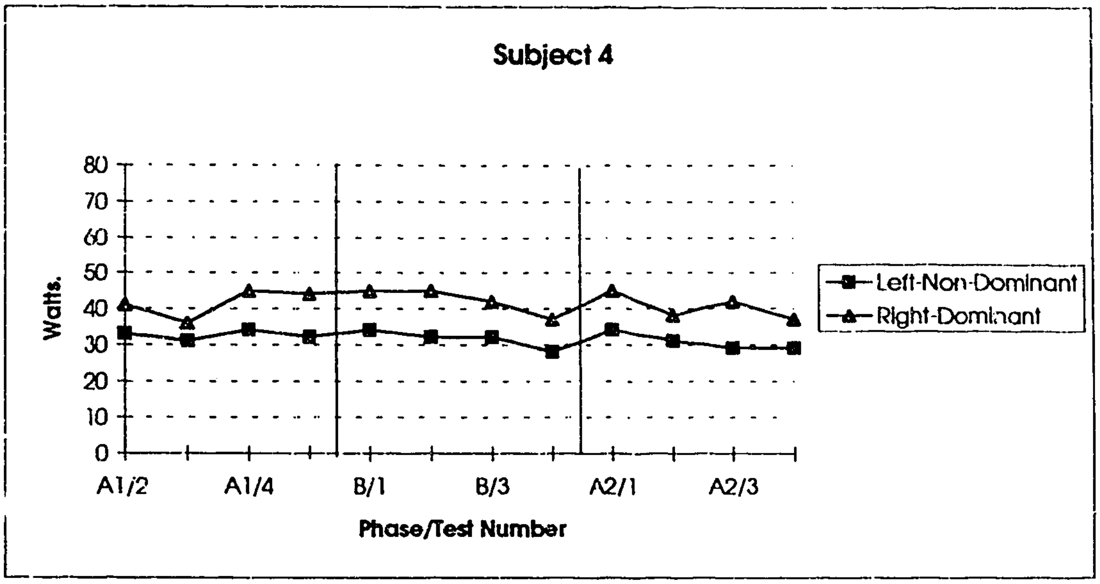


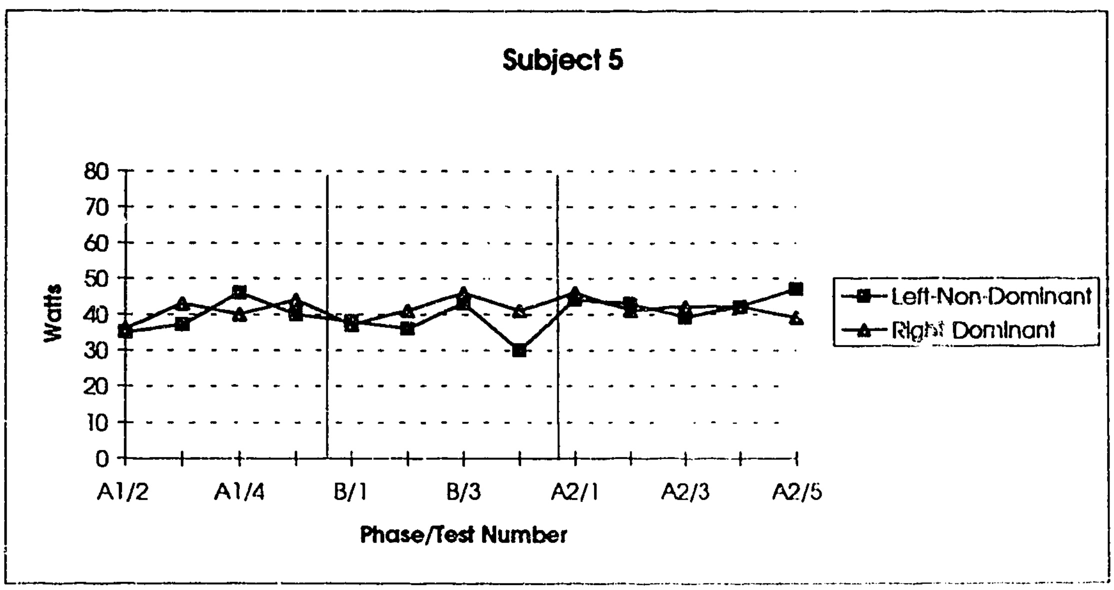




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

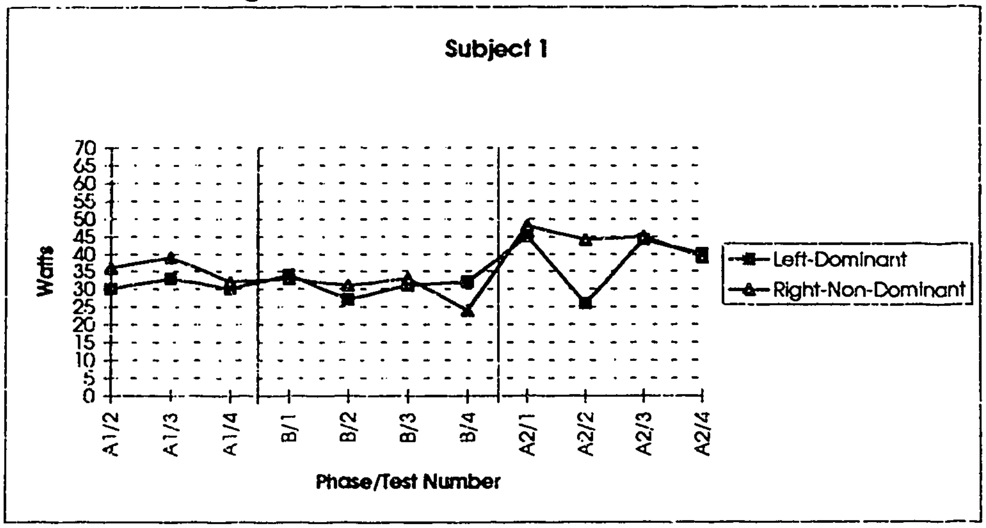
Average Power Extension 0.52 rad·sec^{-1}

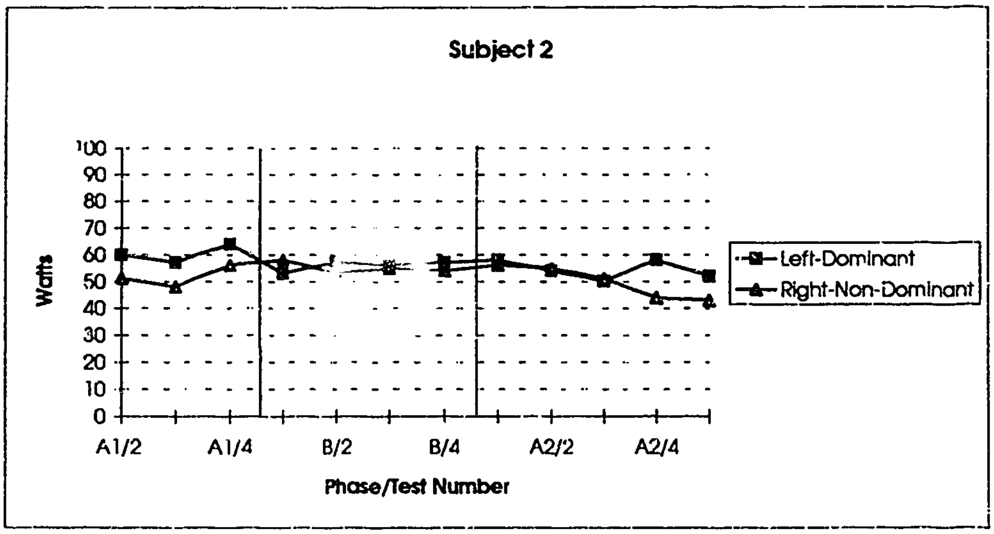


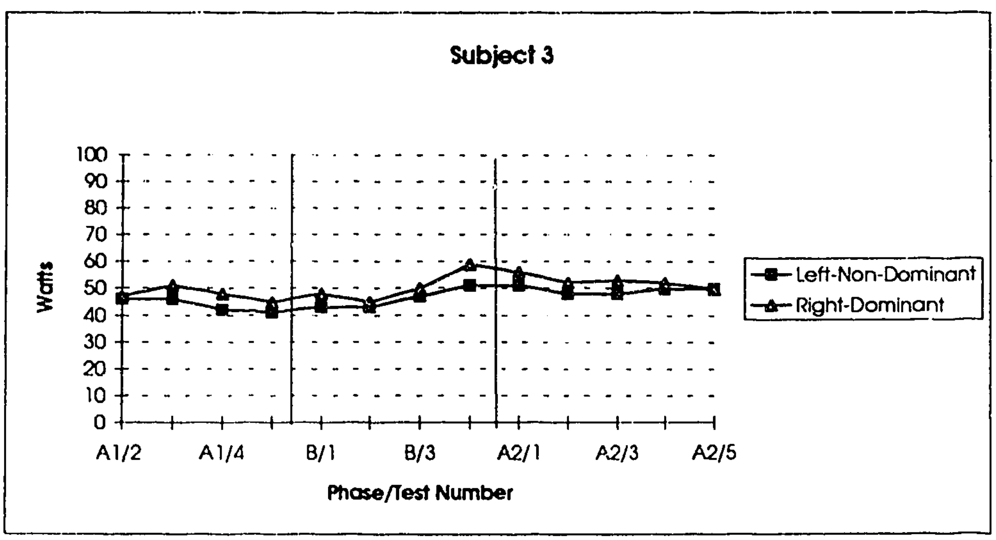


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Average Power Flexion 1.05 rad·sec⁻¹

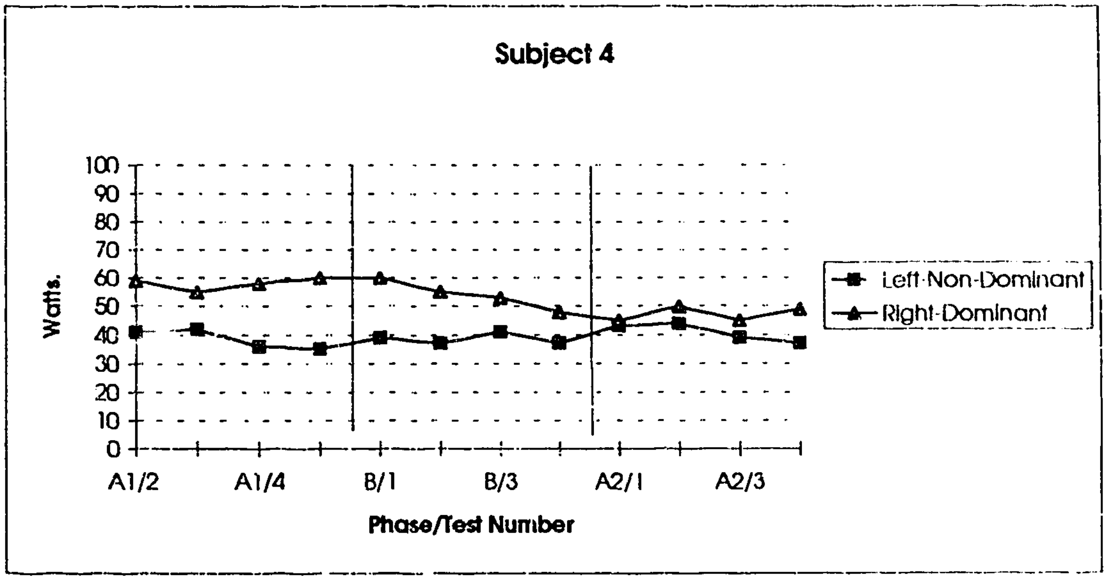


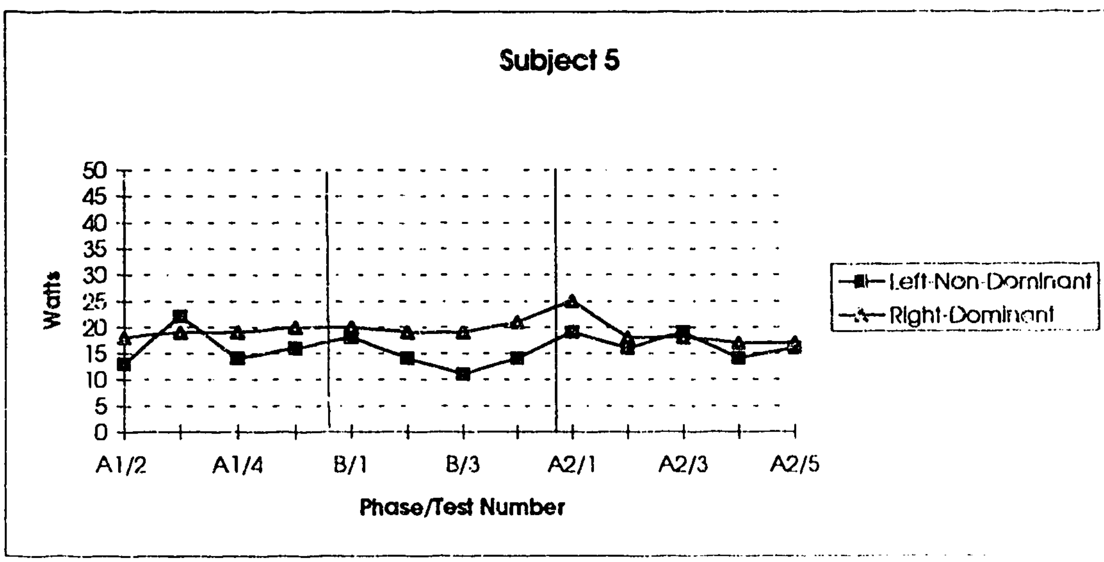




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

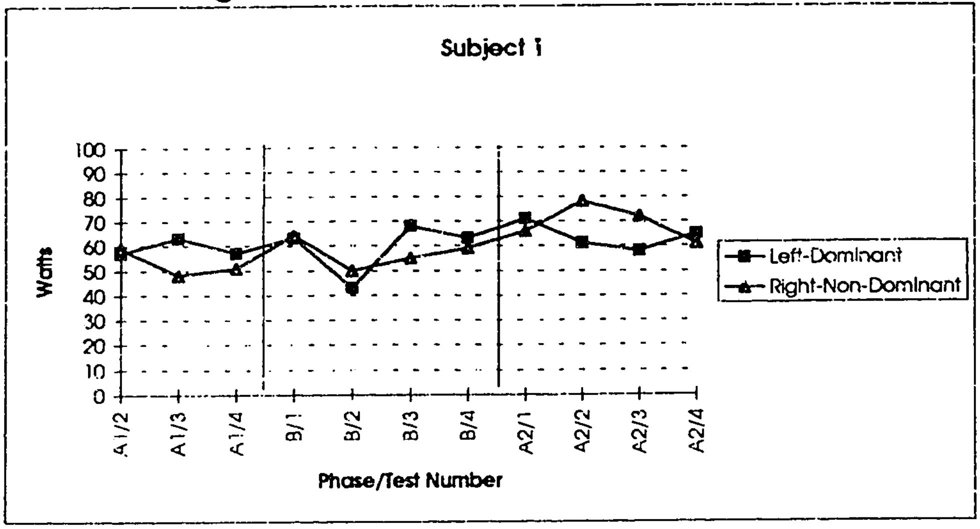
Average Power Flexion 1.05 rad·sec^{-1}

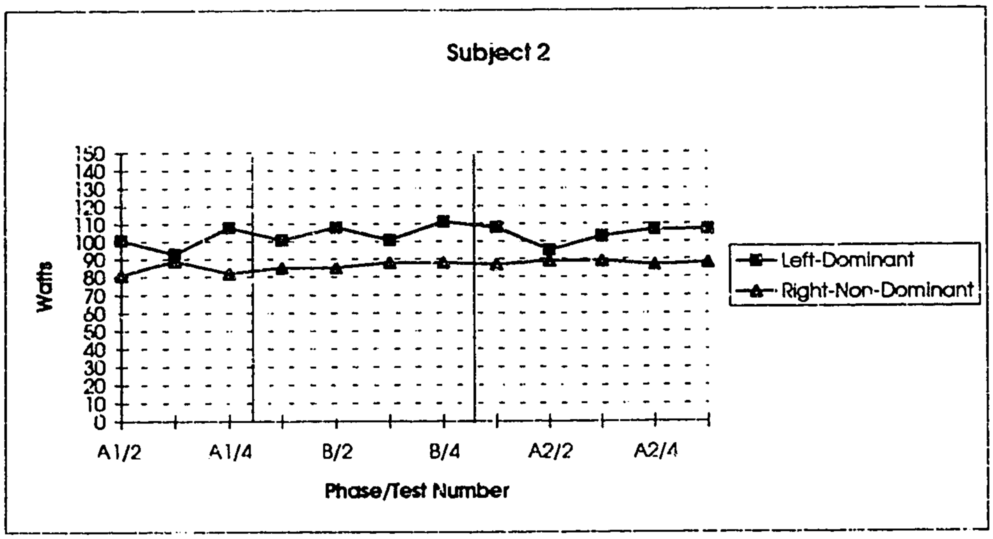


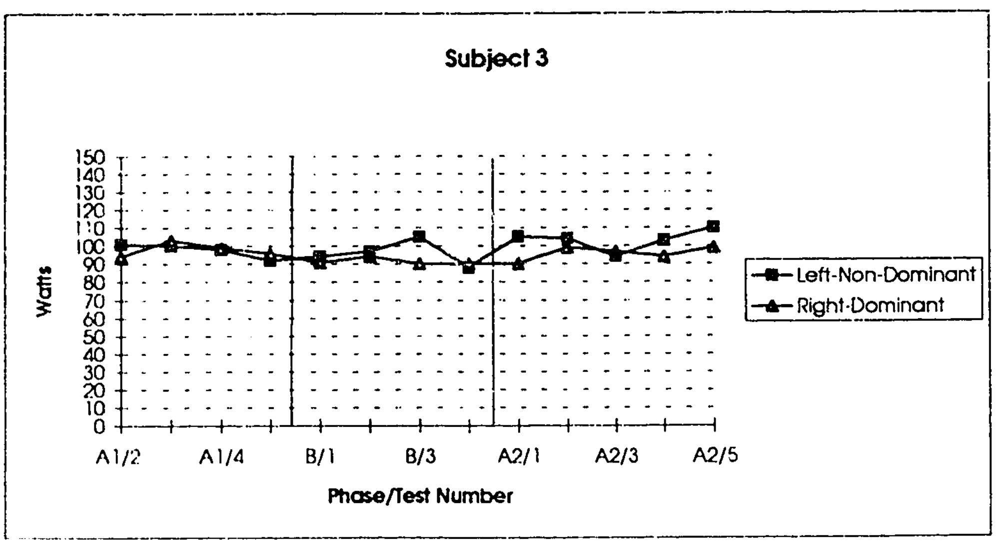


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Average Power Extension 1.05 rad·sec⁻¹

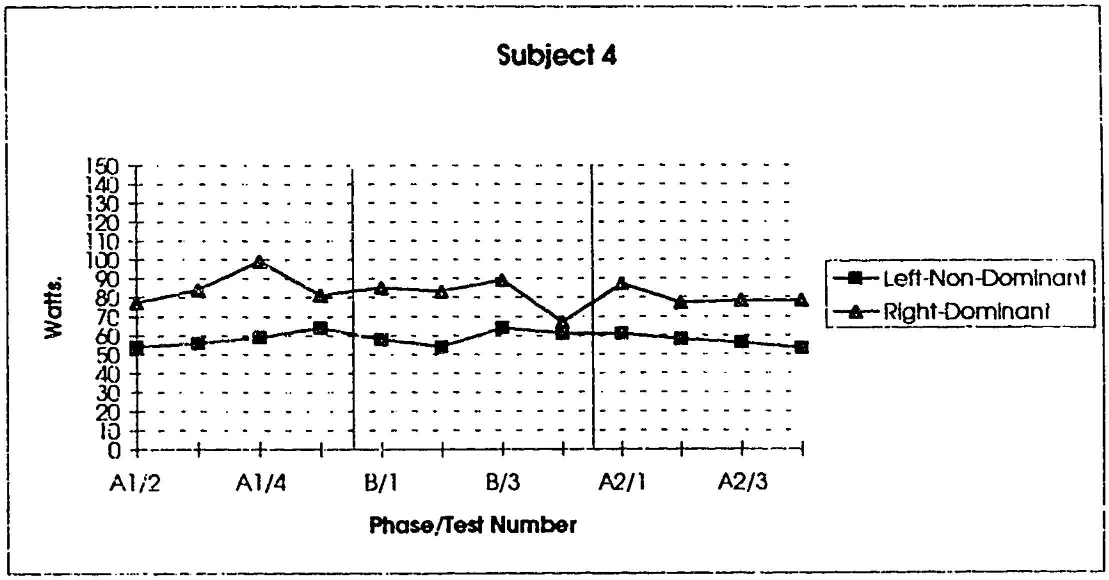


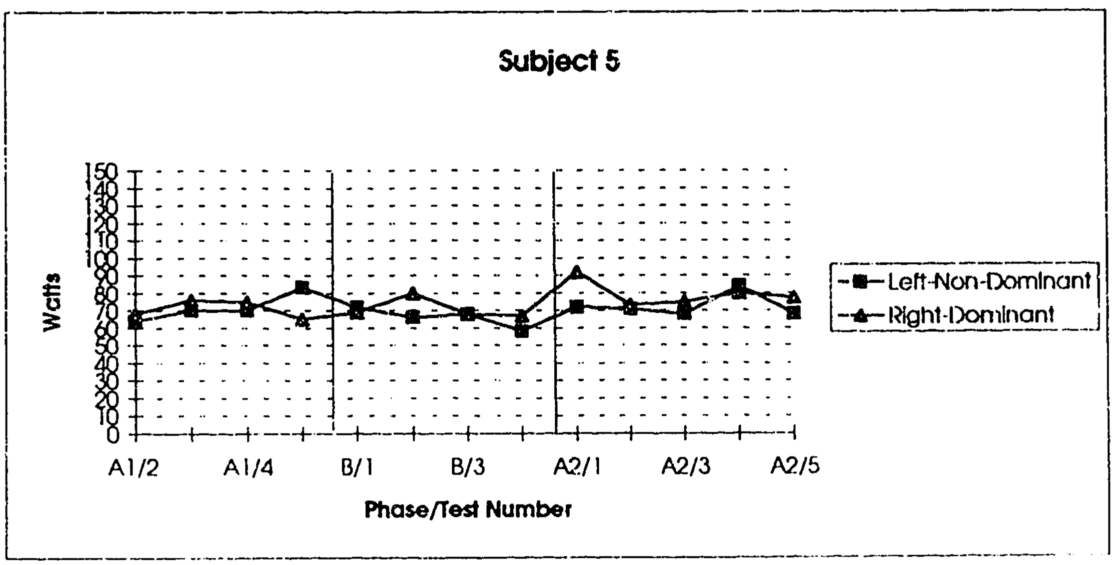




A1 - Baseline Phase   B - Intervention Phase   A2 - Withdrawal Phase

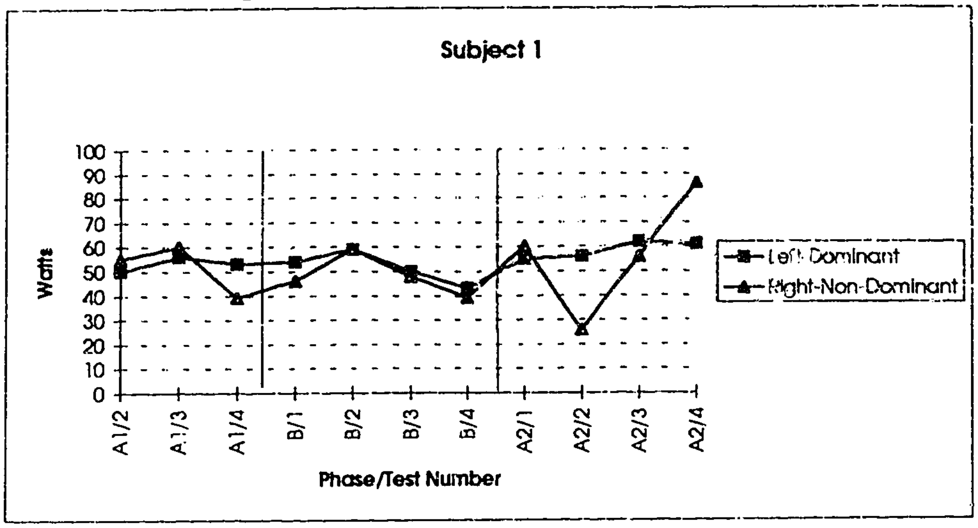
Average Power Extension 1.05 rad·sec^{-1}

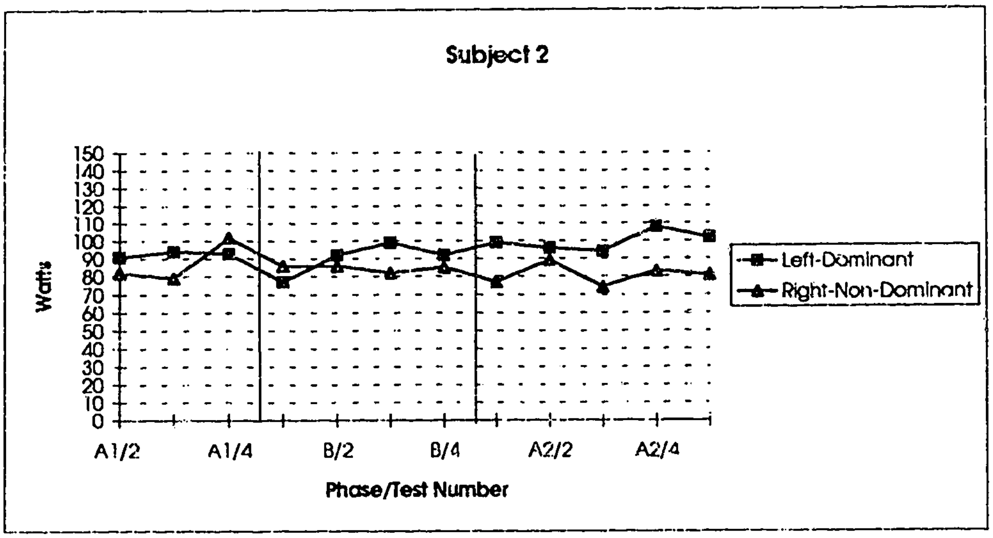


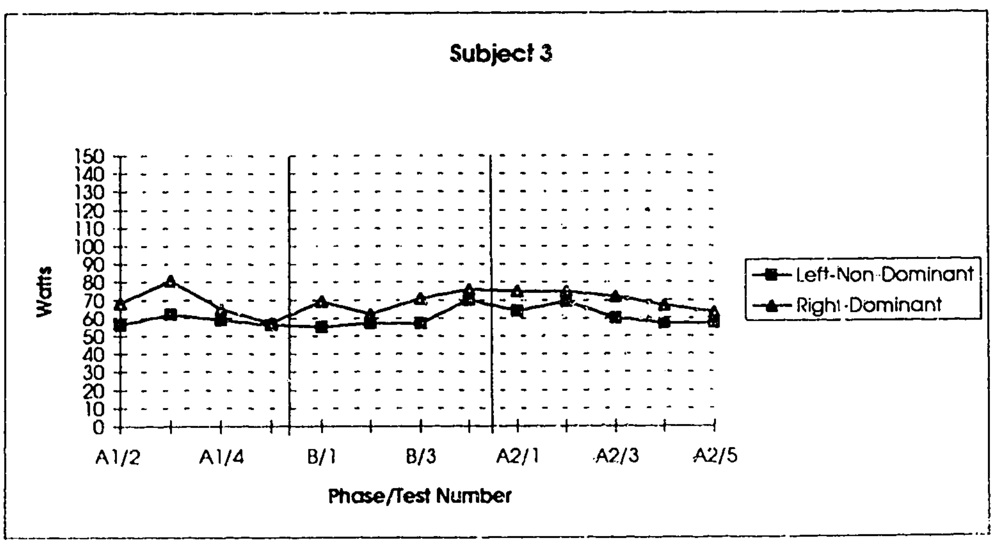


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Average Power Flexion 2.09 rad·sec^{-1}

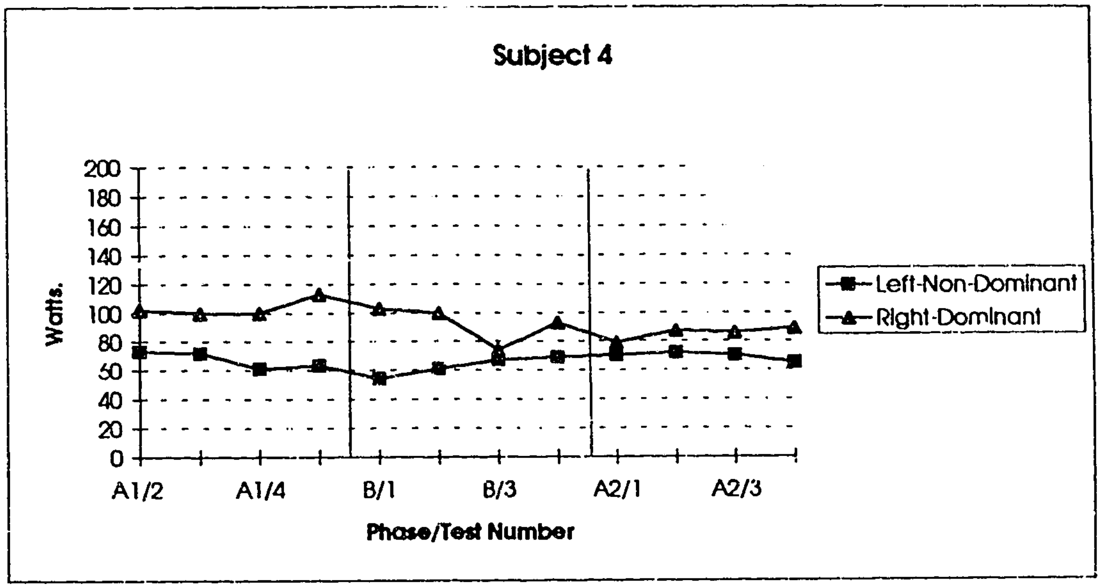


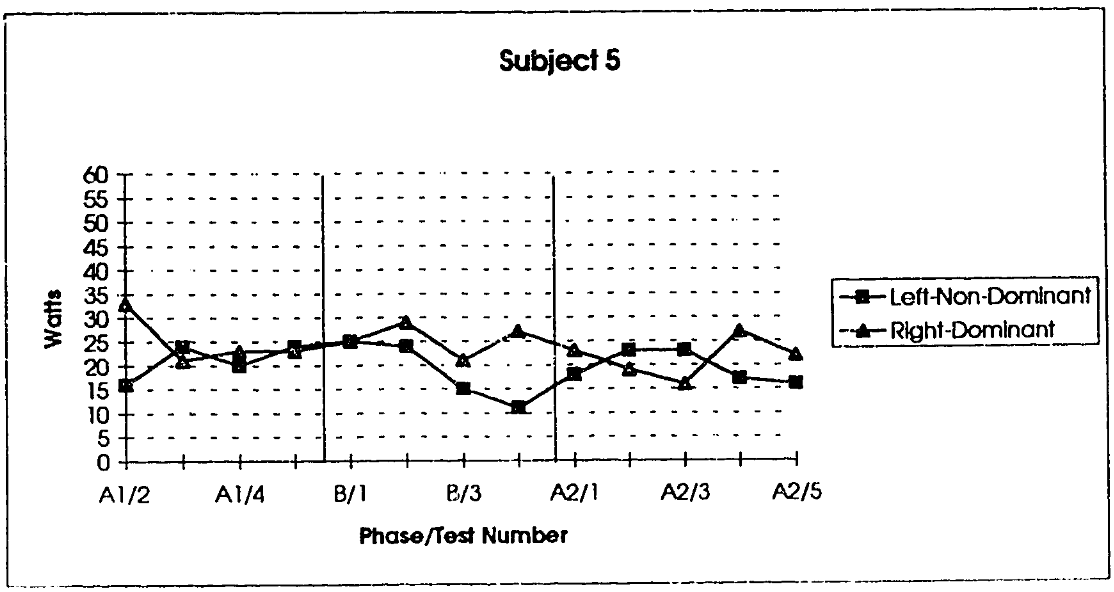




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

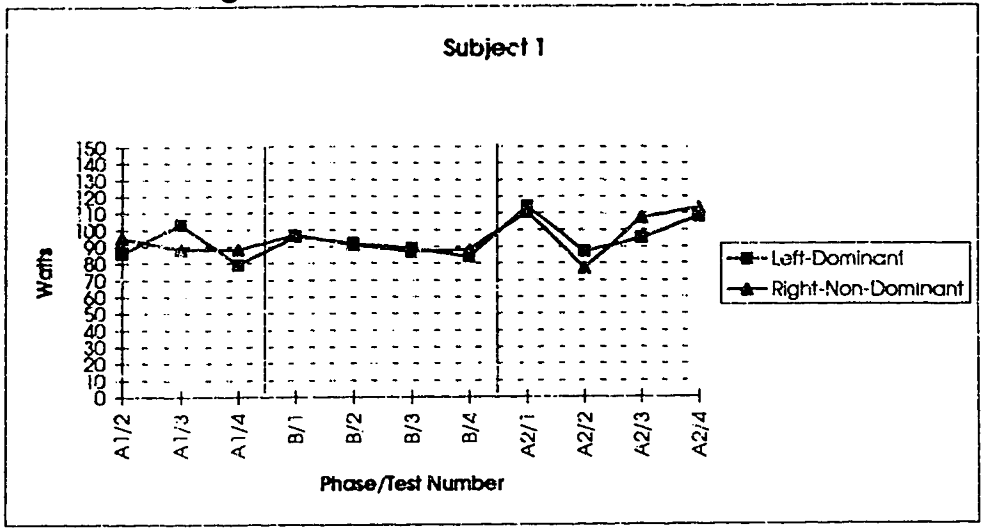
Average Power Flexion 2.09 rad·sec^{-1}

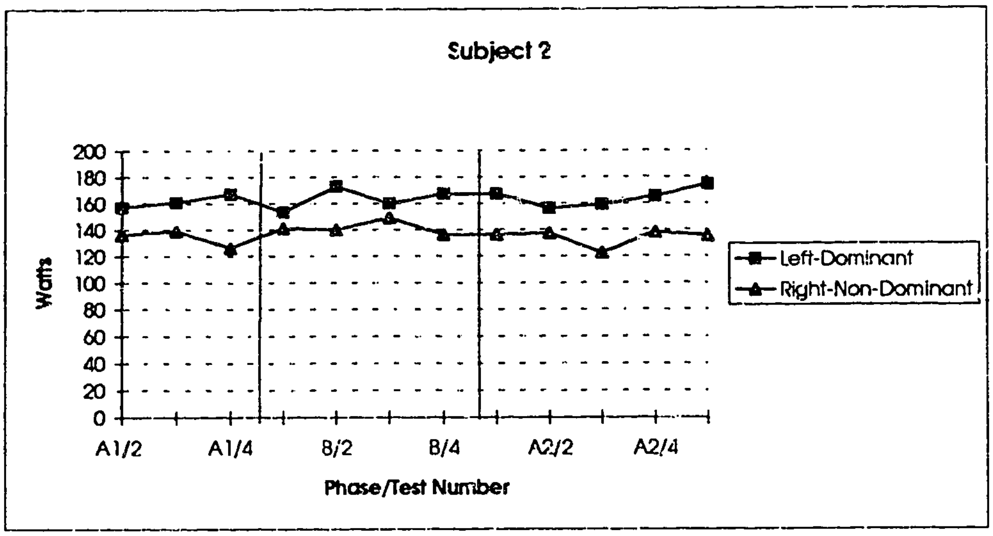


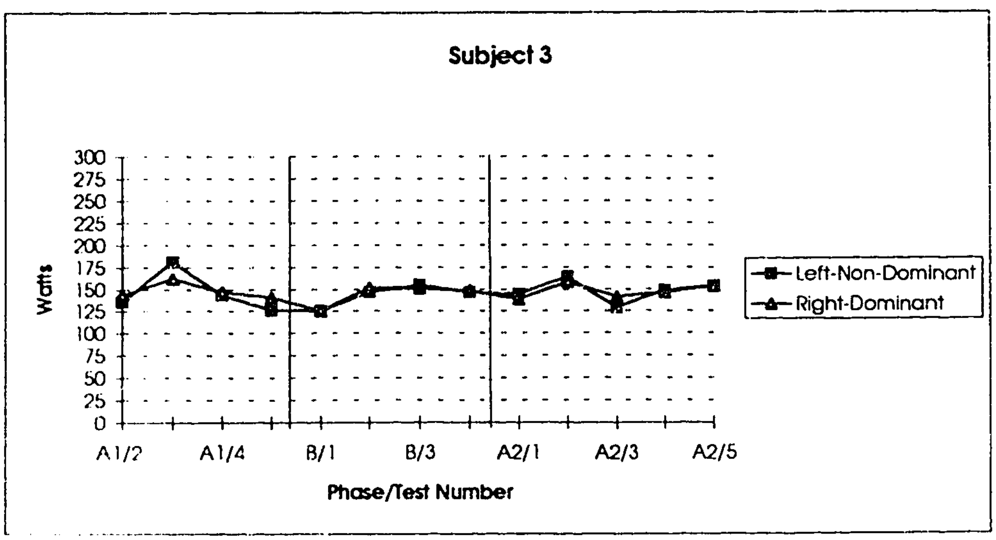


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Average Power Extension 2.09 rad·sec⁻¹

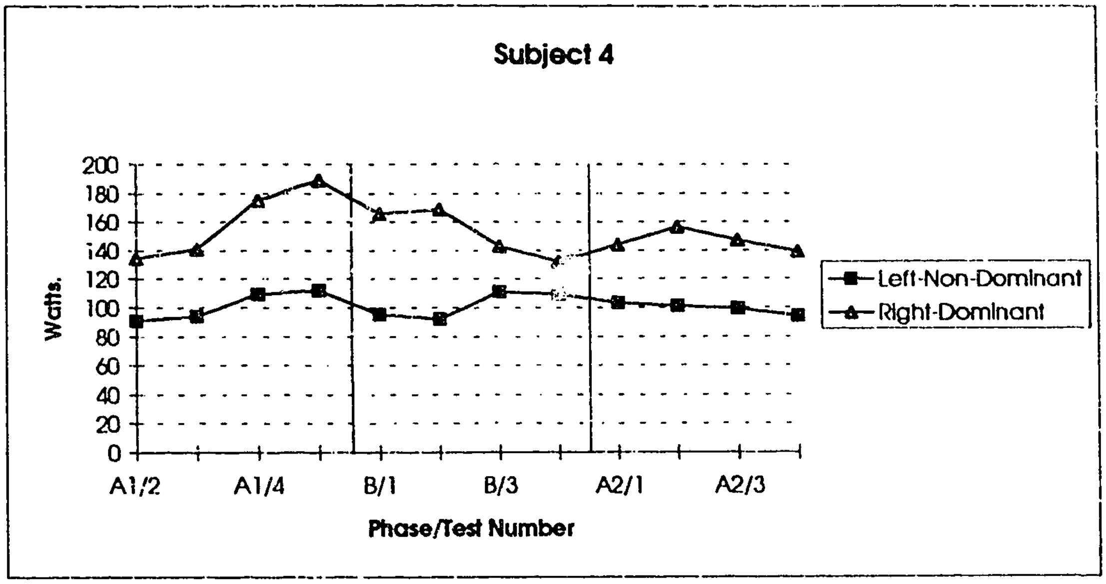


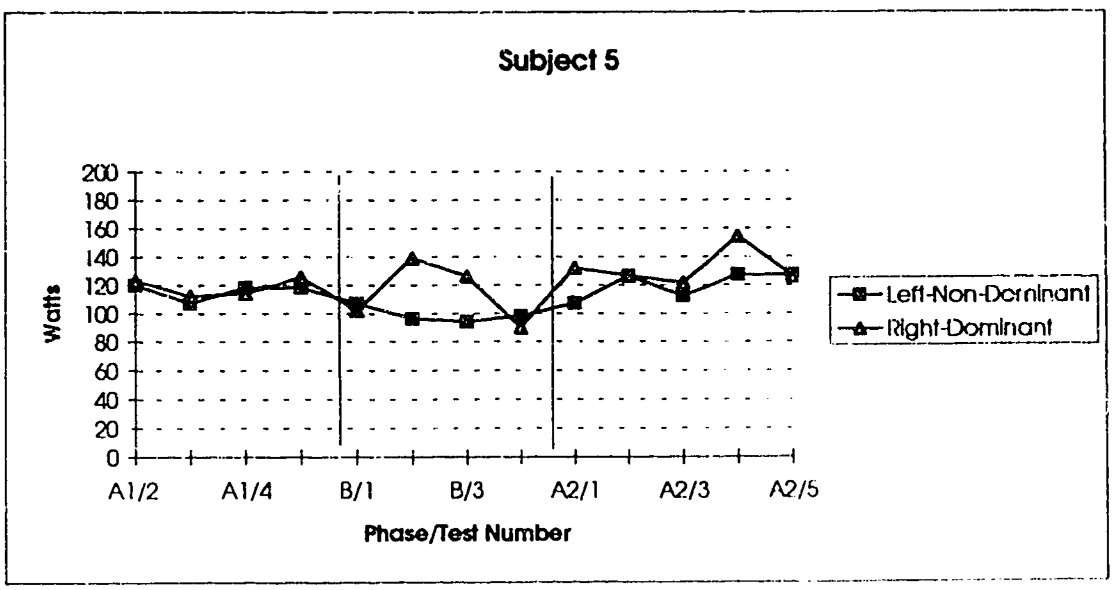




A1 Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

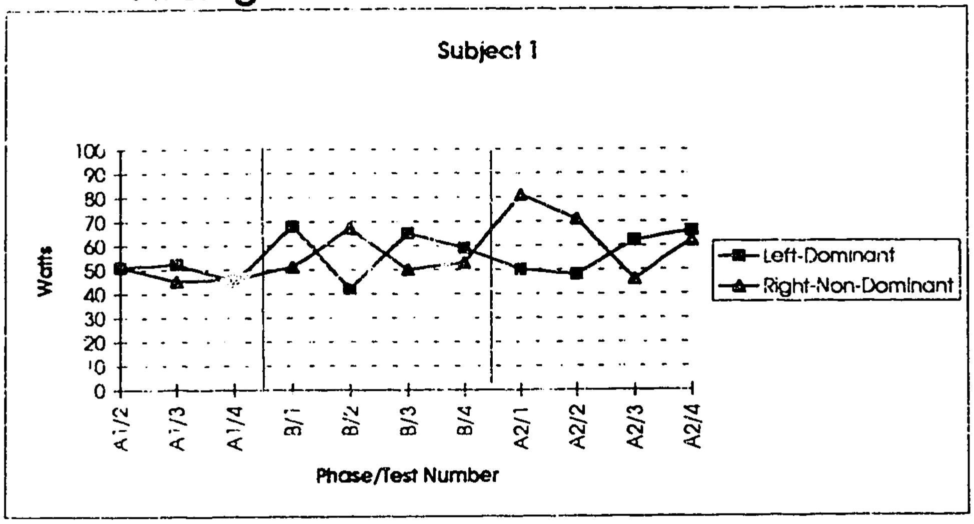
Average Power Extension 2.09 rad·sec^{-1}

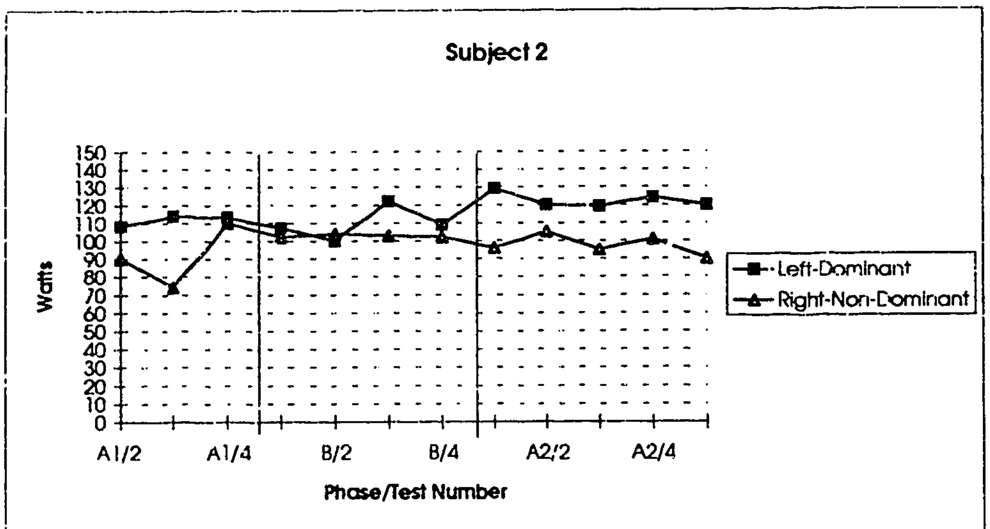


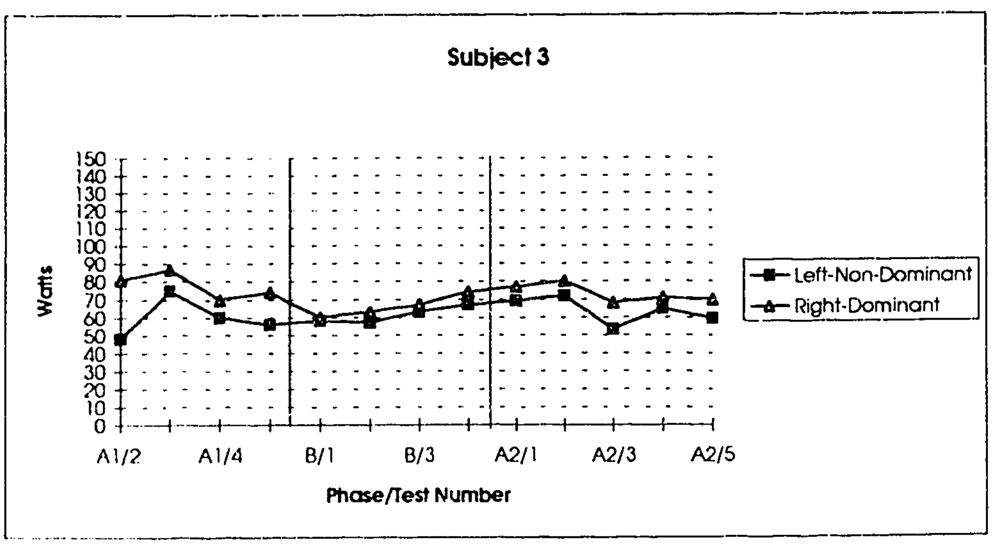


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Average Power Flexion 3.14 rad·sec⁻¹

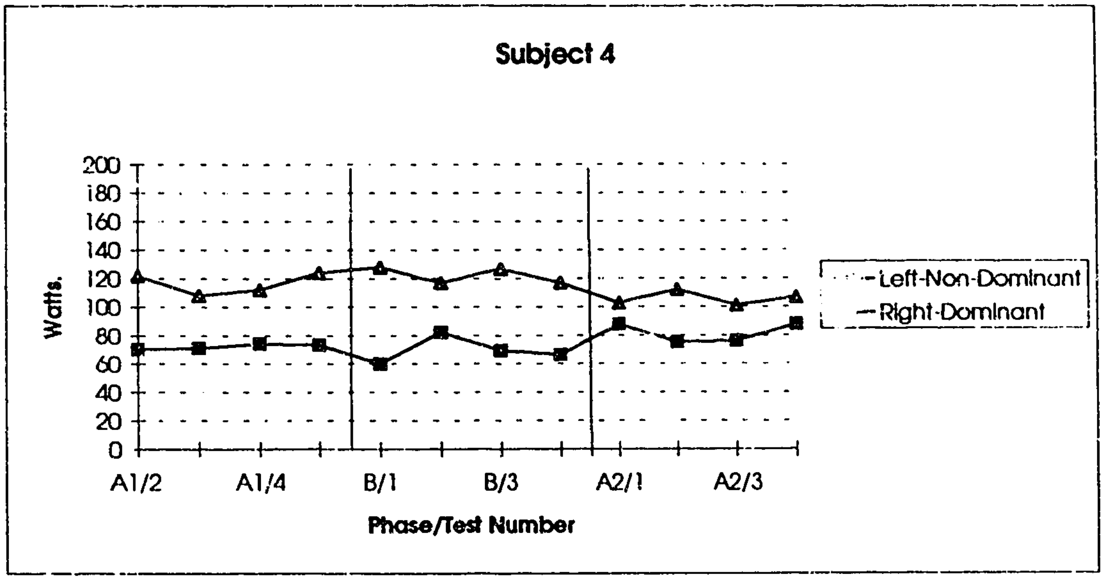


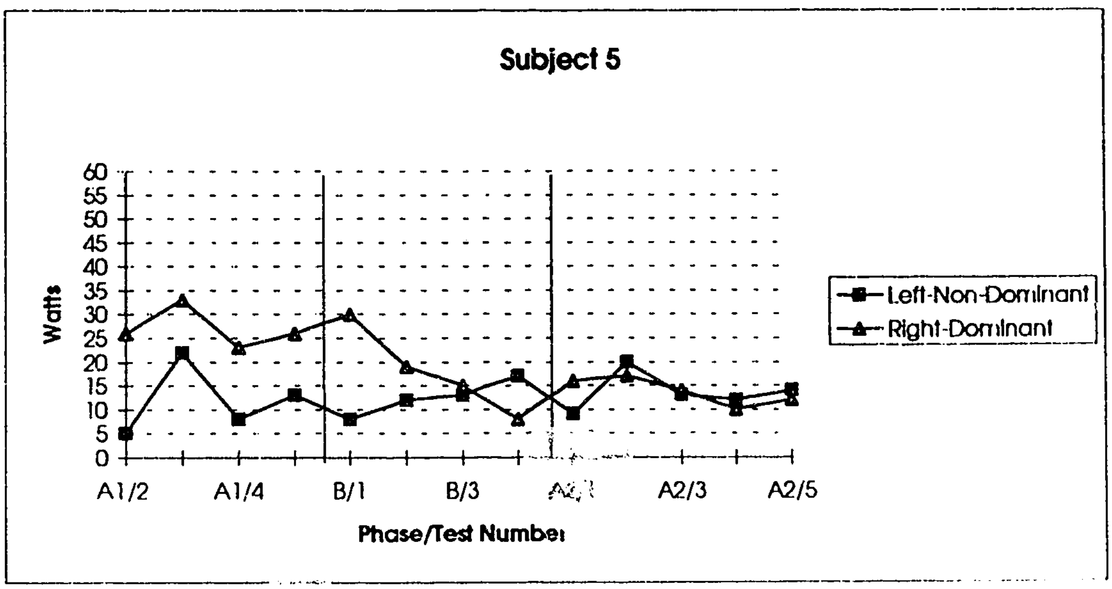




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

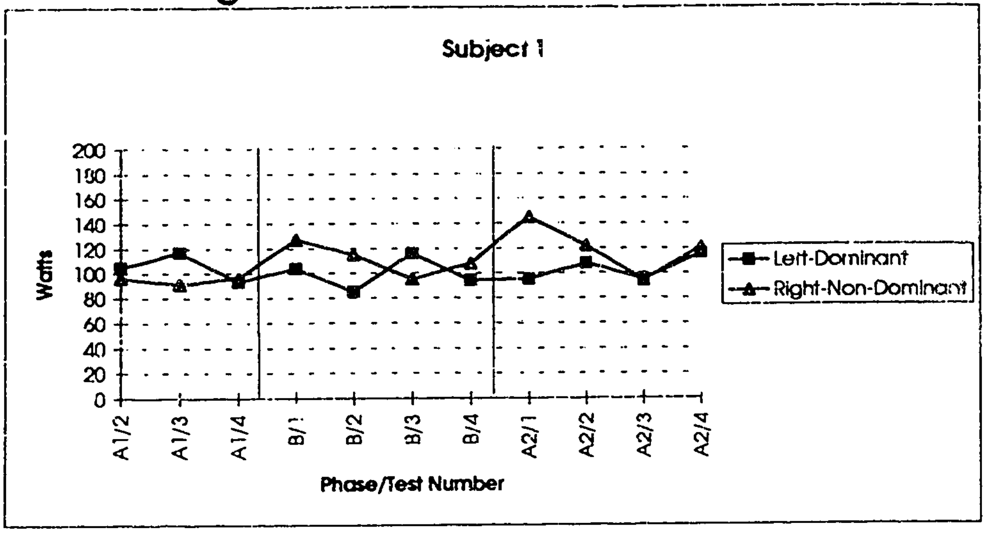
Average Power Flexion 3.14 rad·sec⁻¹

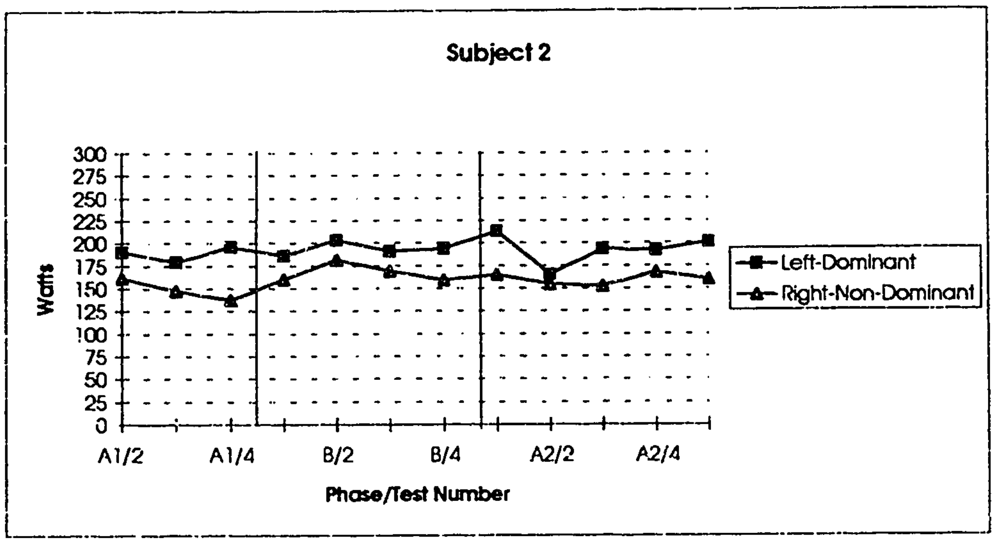


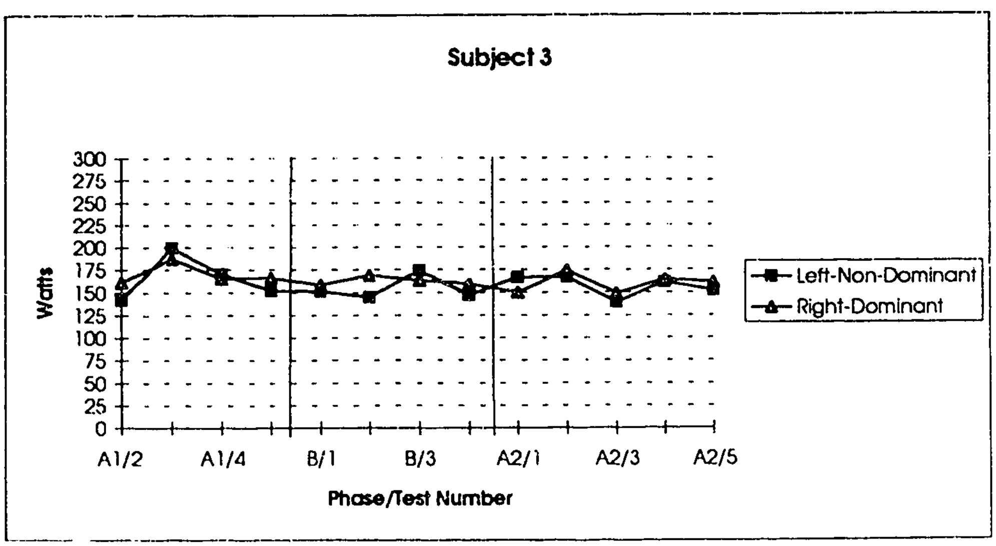


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Average Power Extension 3.14 rad sec^{-1}

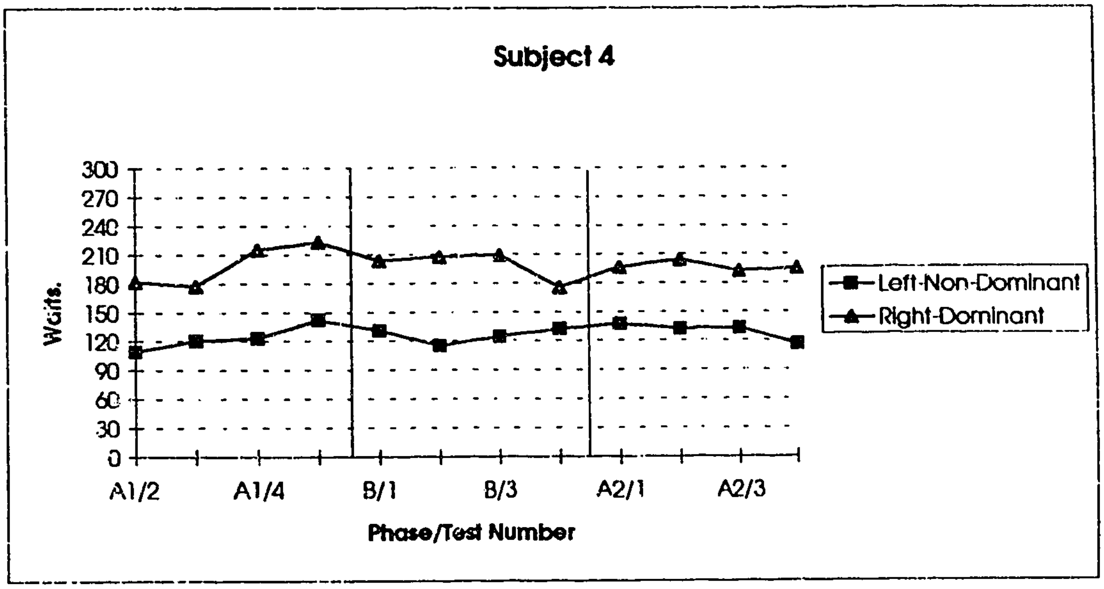


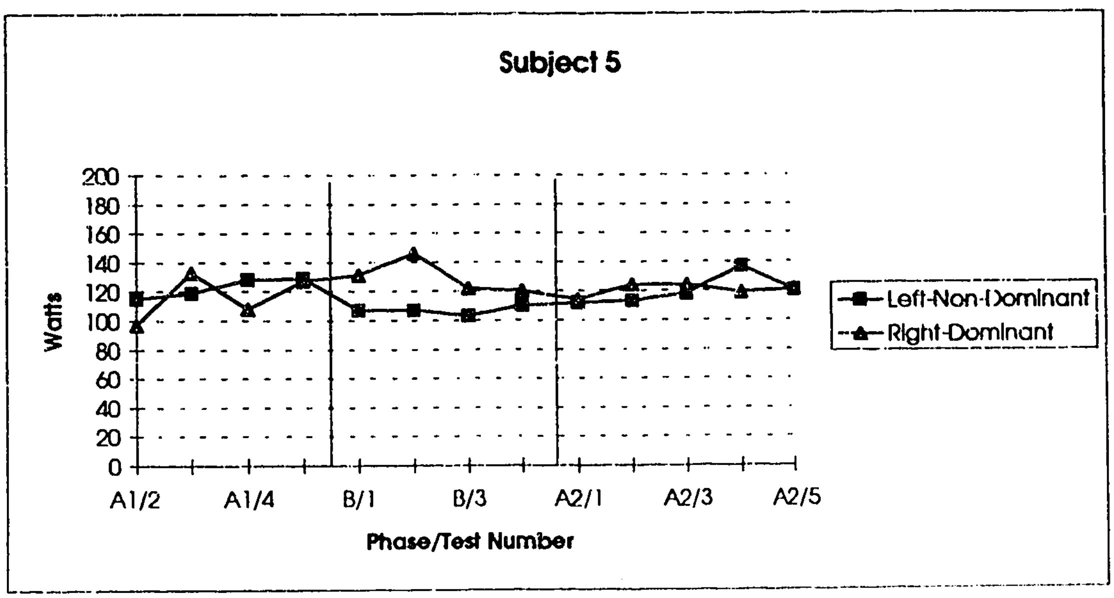




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

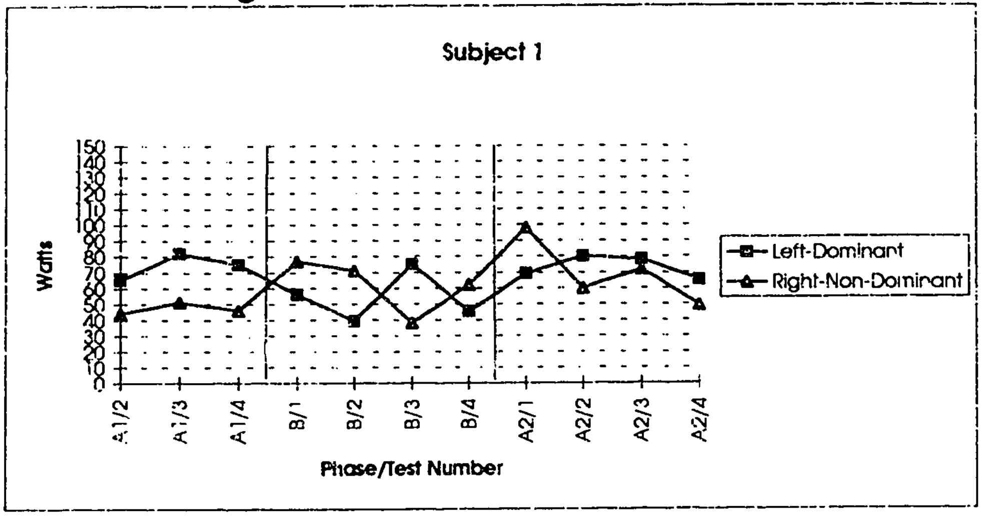
Average Power Extension 3.14 rad·sec⁻¹

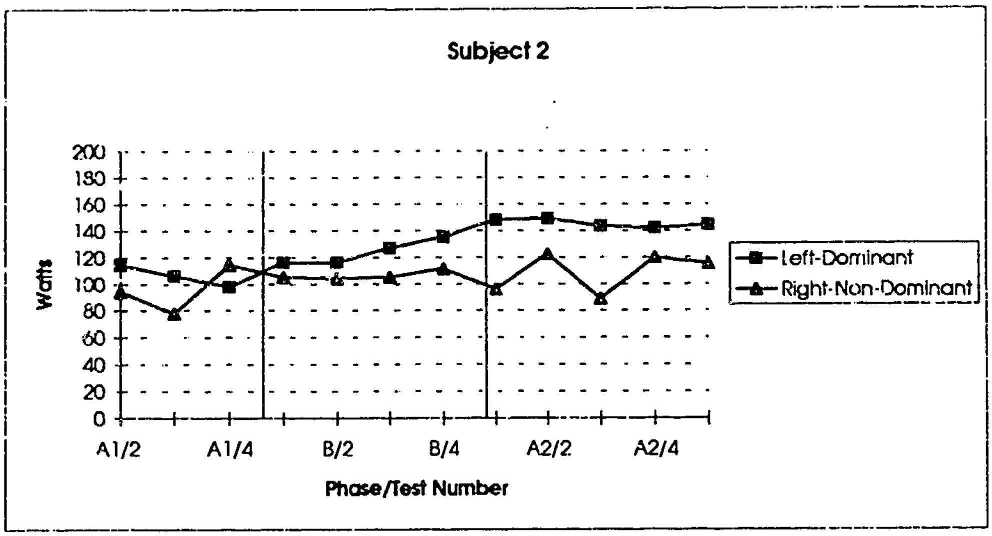


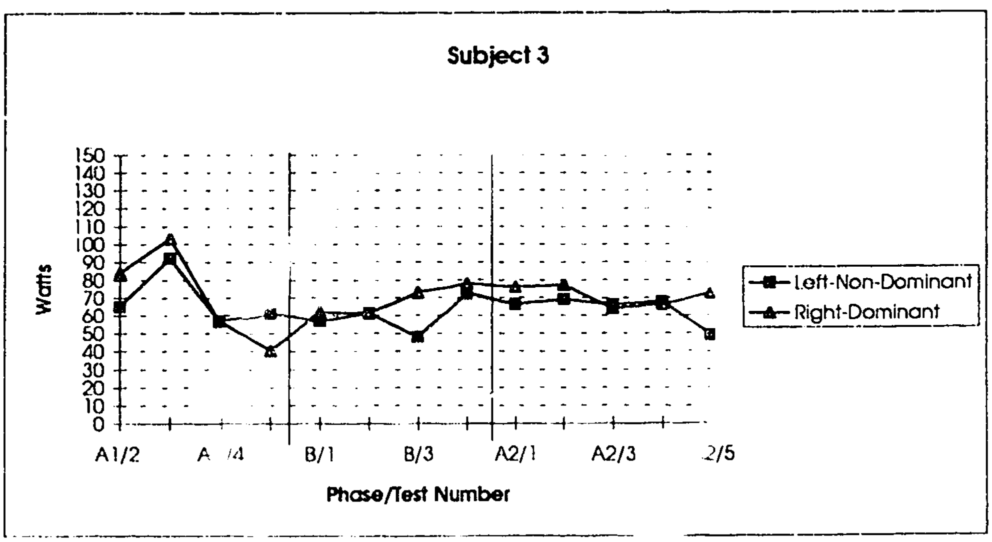


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Average Power Flexion 4.19 rad·sec^{-1}

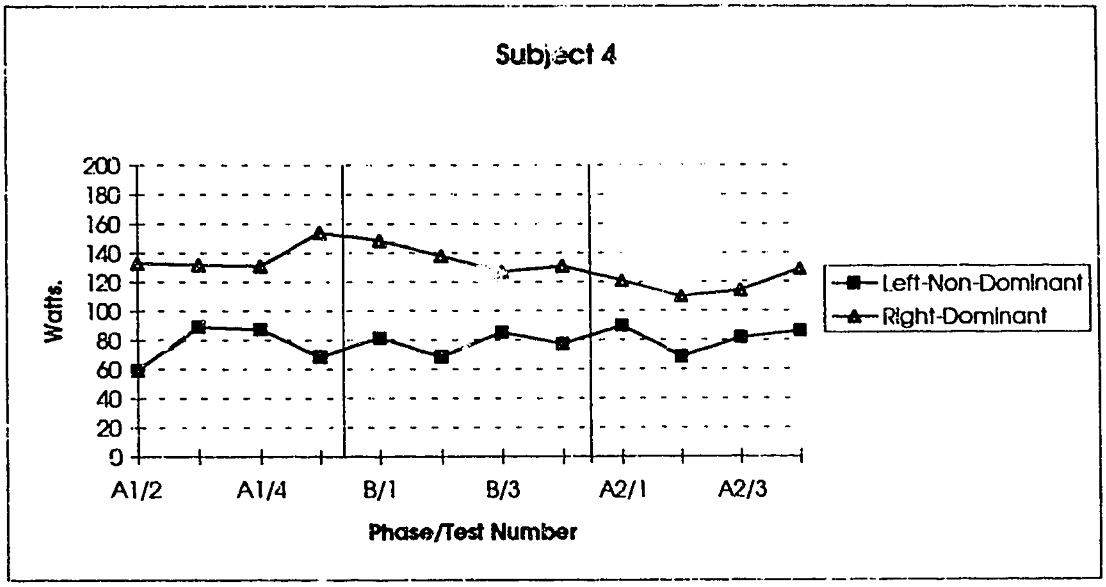


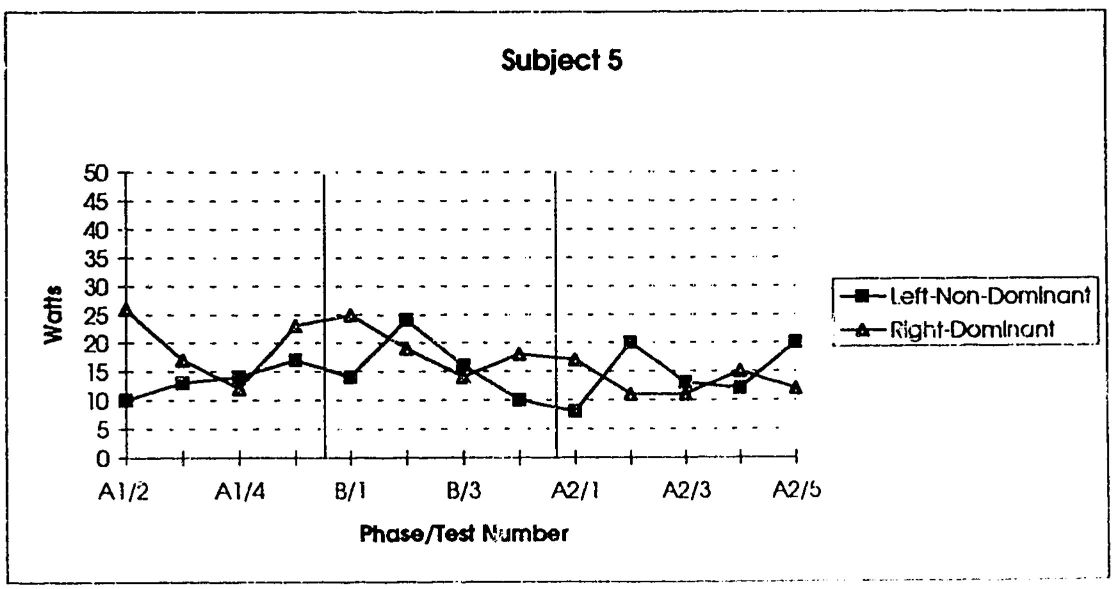




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

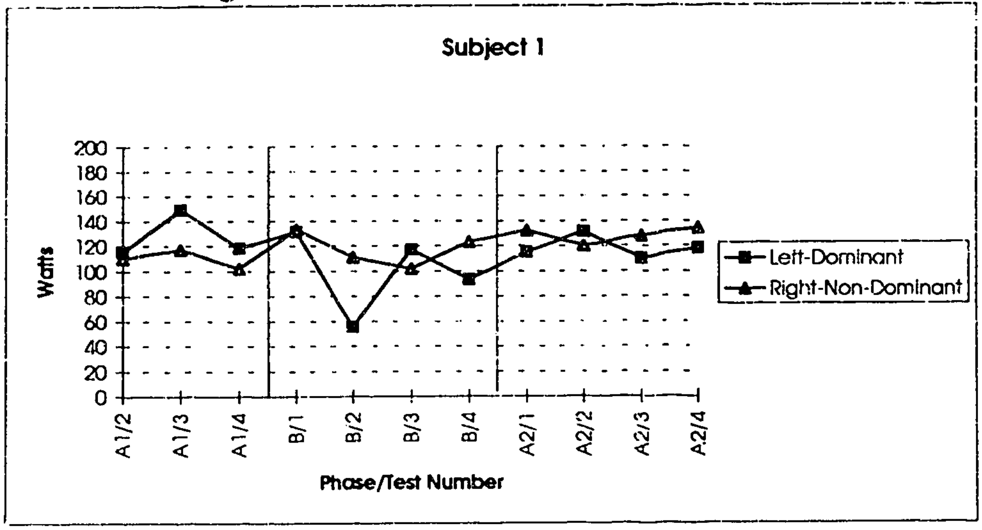
Average Power Flexion 4.19 rad·sec^{-1}

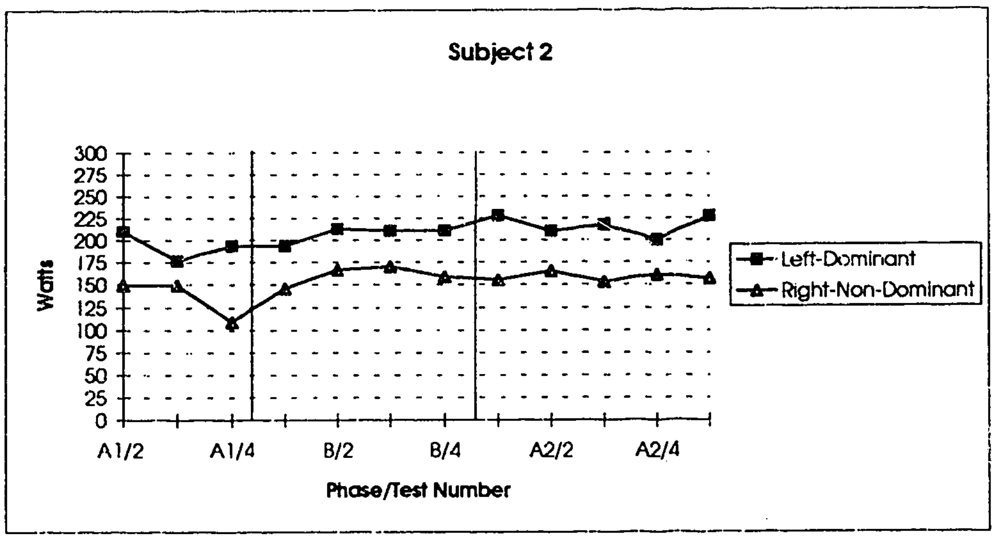


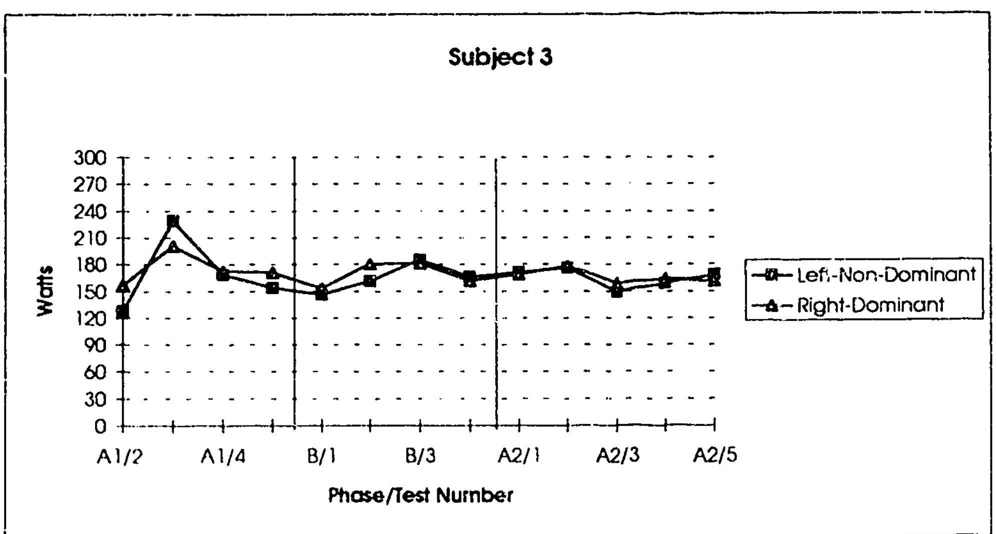


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Average Power Extension 4.19 $rad \cdot sec^{-1}$

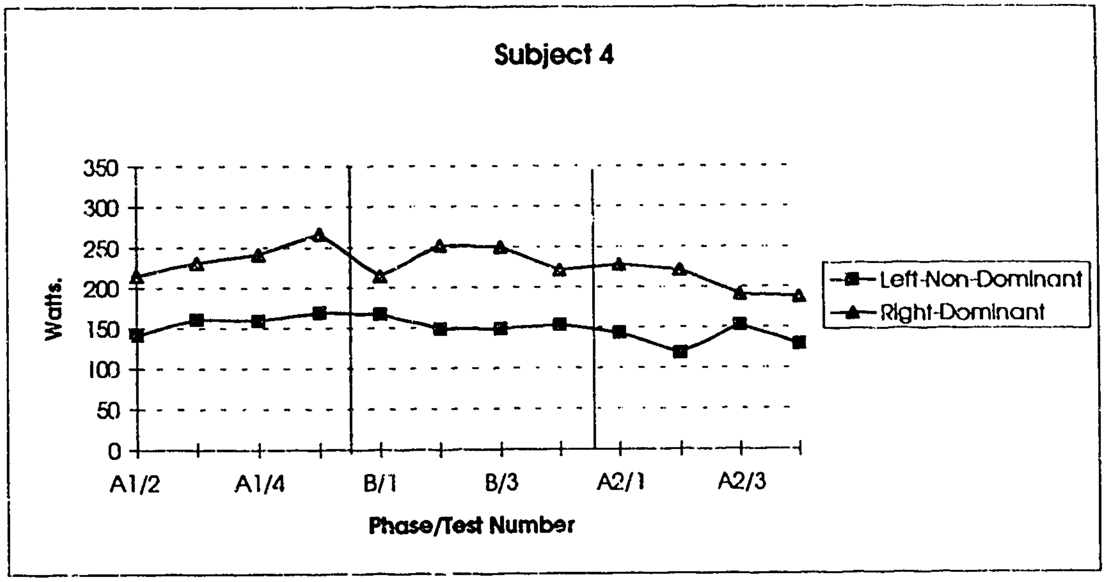


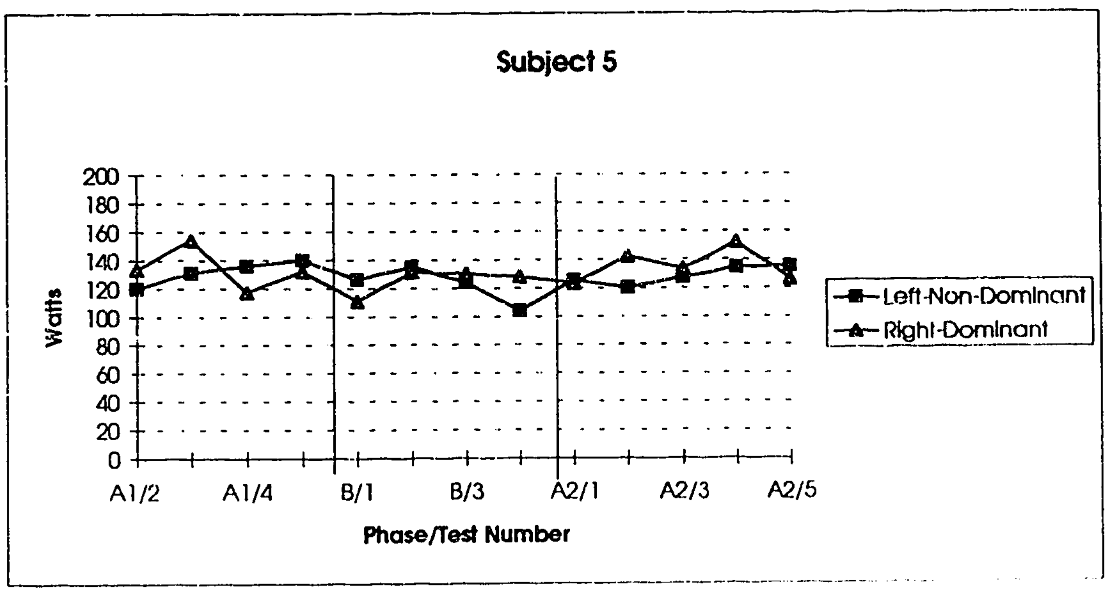




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

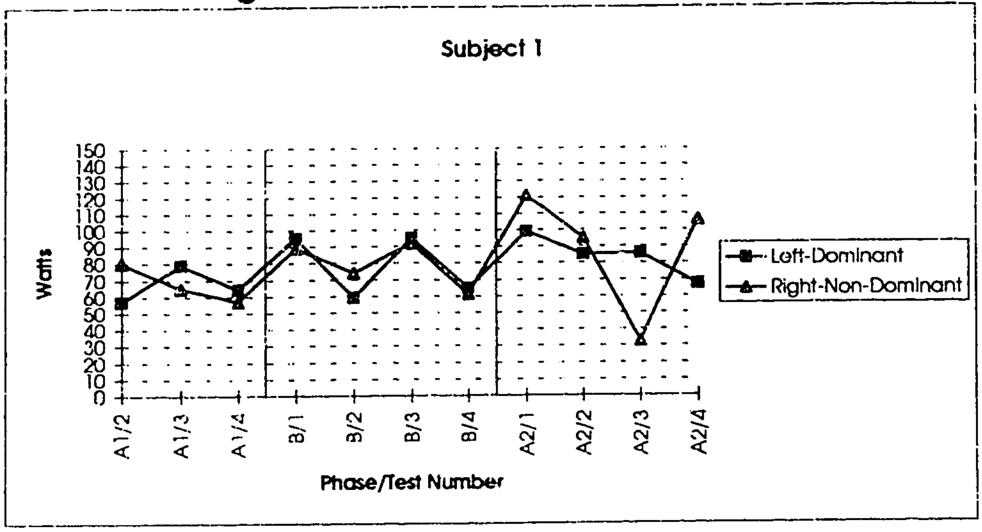
Average Power Extension 4.19 rad·sec^{-1}

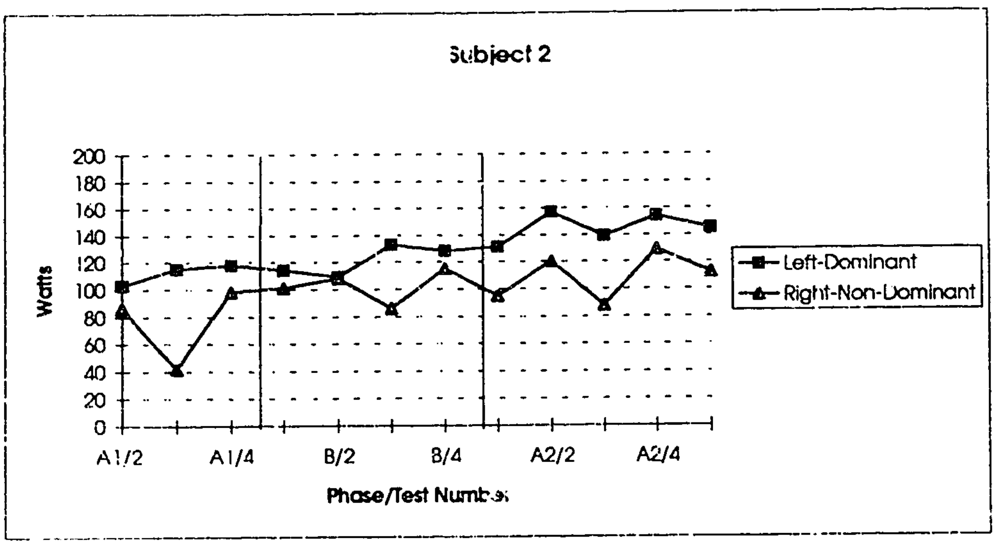


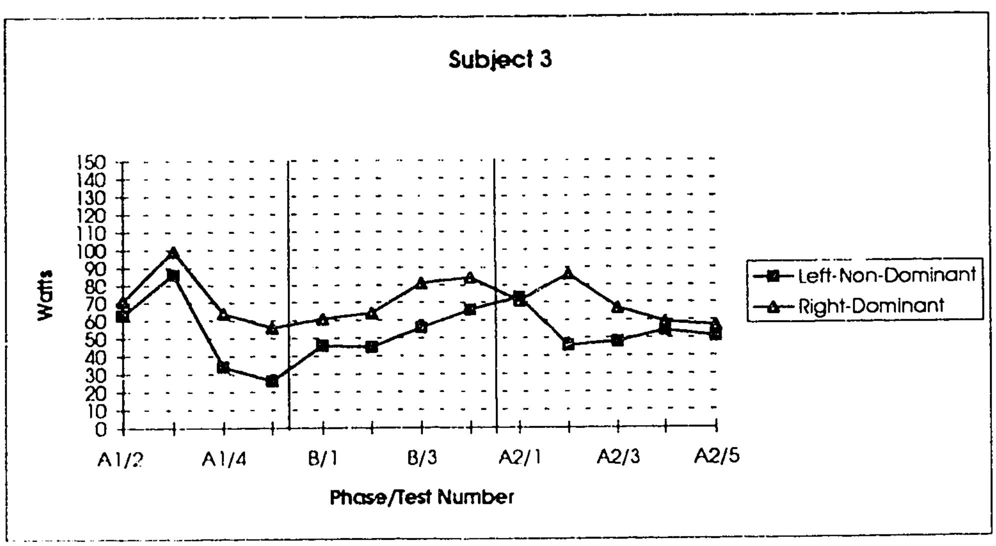


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Average Power Flexion 5.24 rad·sec^{-1}

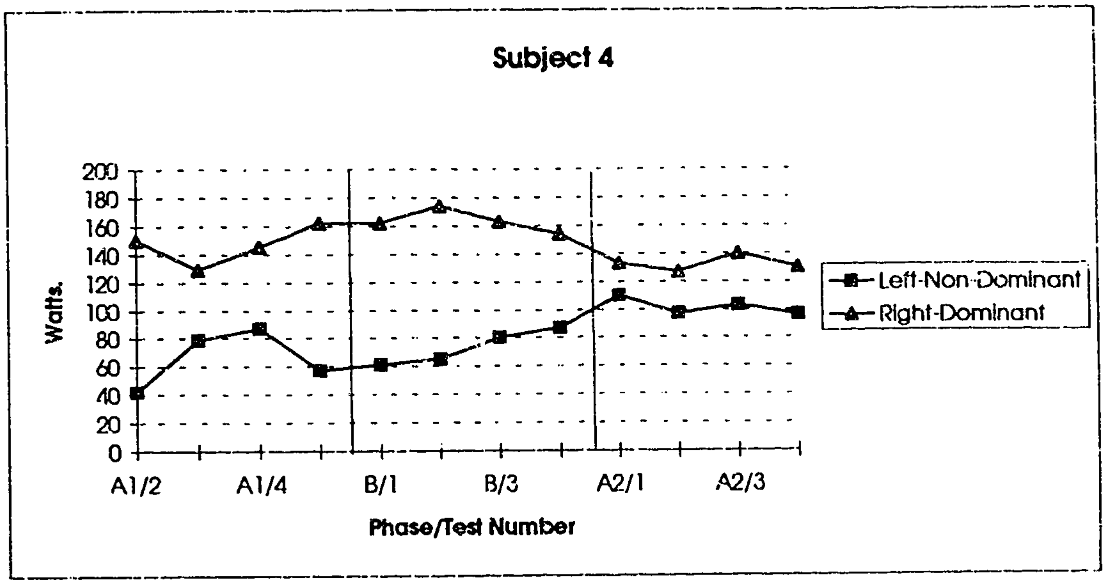


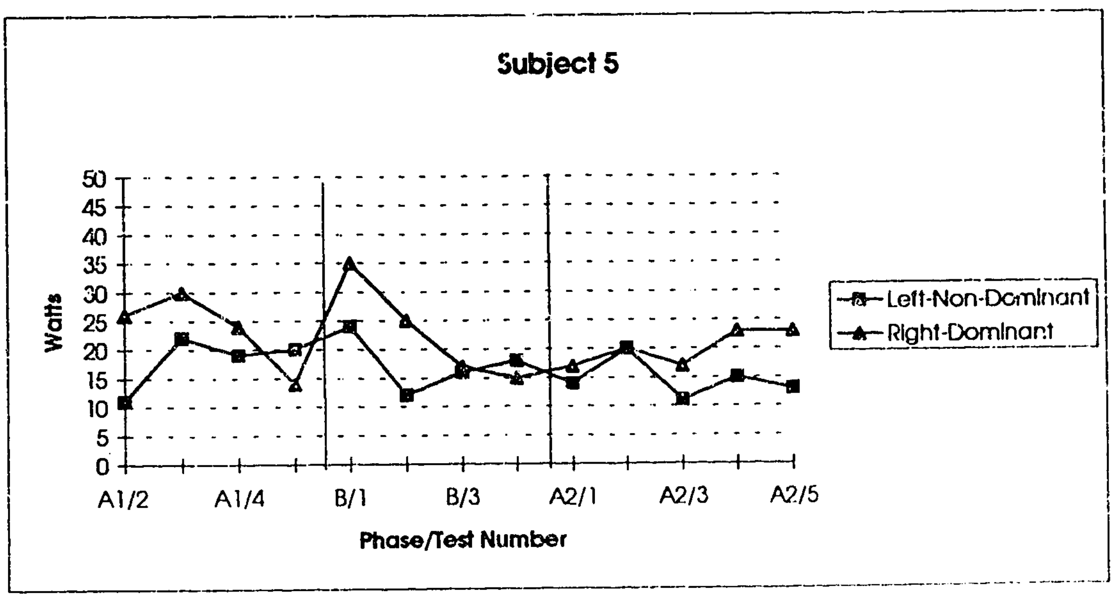




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

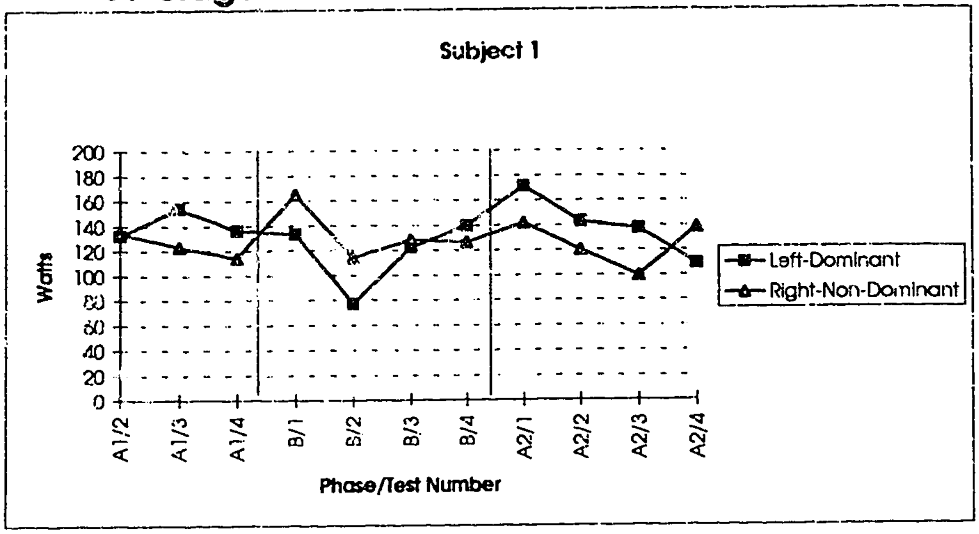
Average Power Flexion 5.24 rad·sec⁻¹

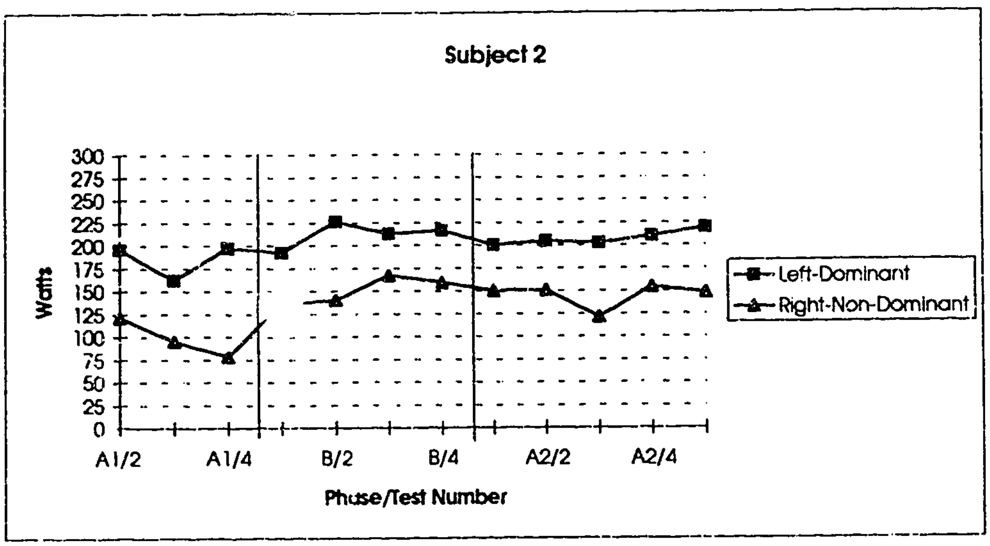


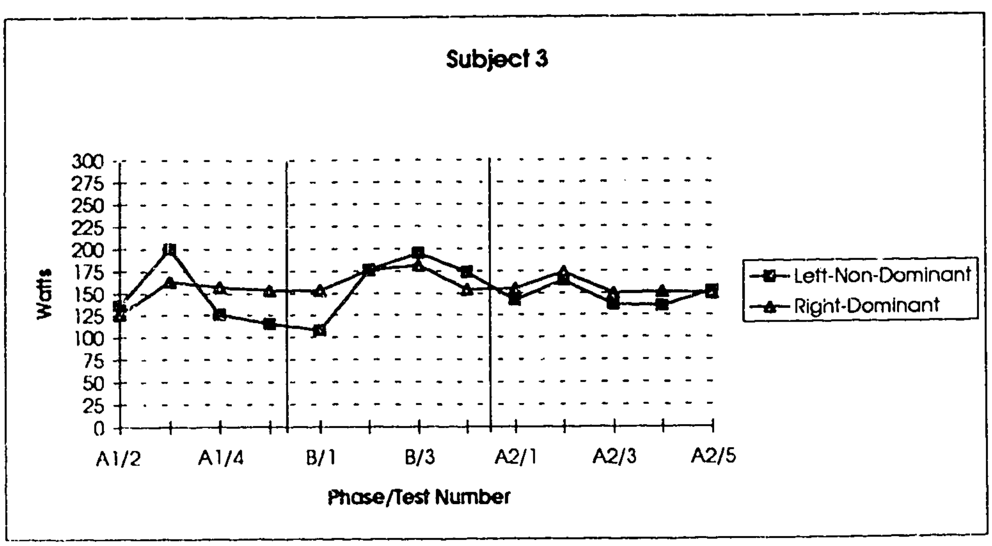


A1 - Baseline Phase   B - Intervention Phase   A2 - Withdrawal Phase

Average Power Extension 5.24 rad·sec⁻¹

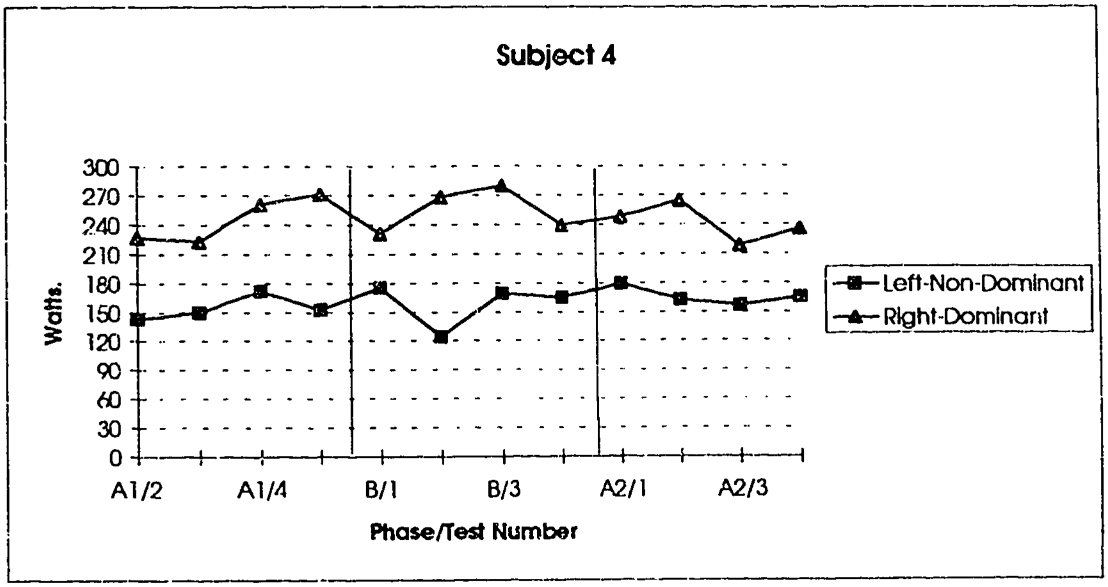


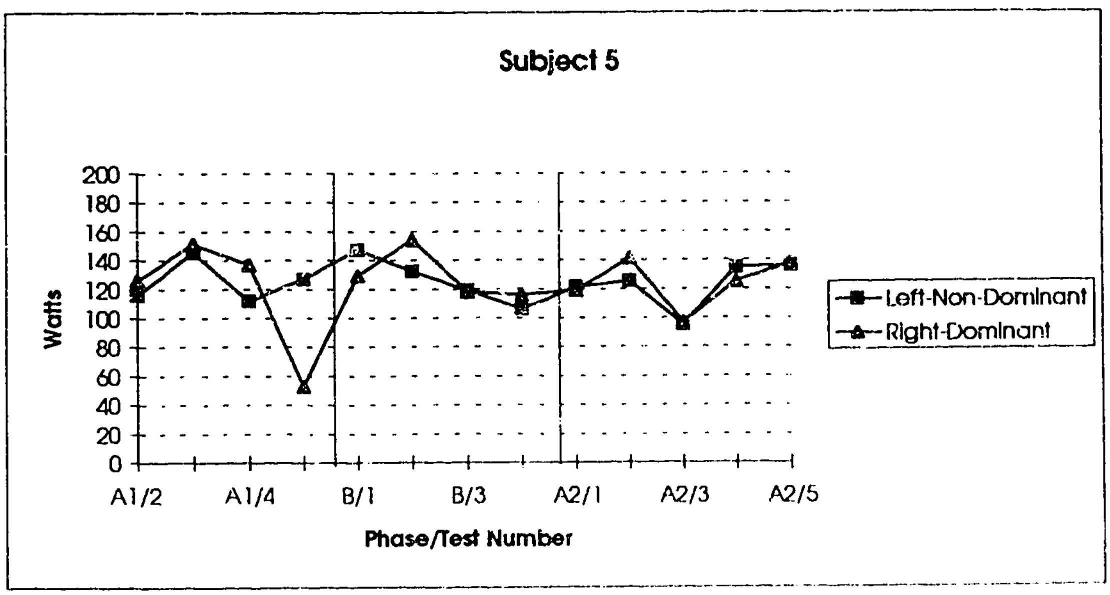




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

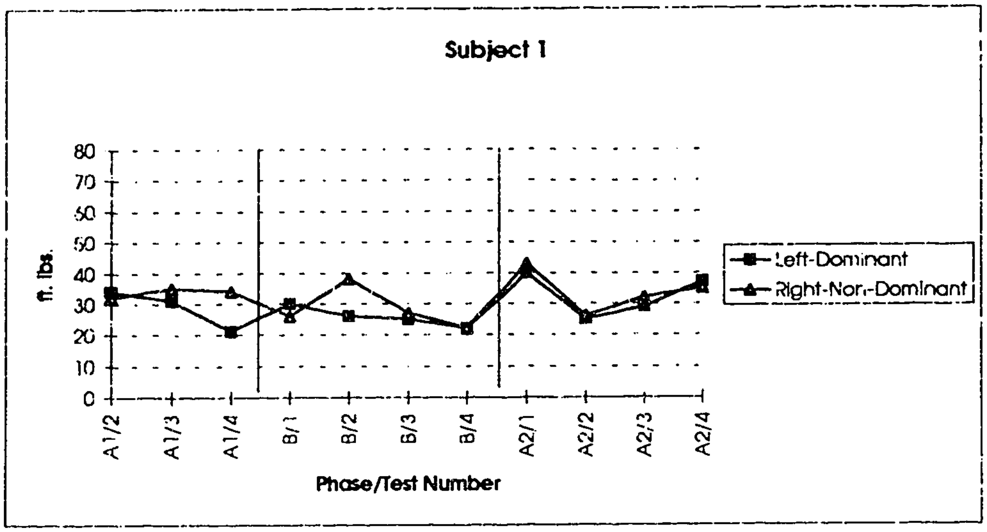
Average Power Extension 5.24 rad sec^{-1}

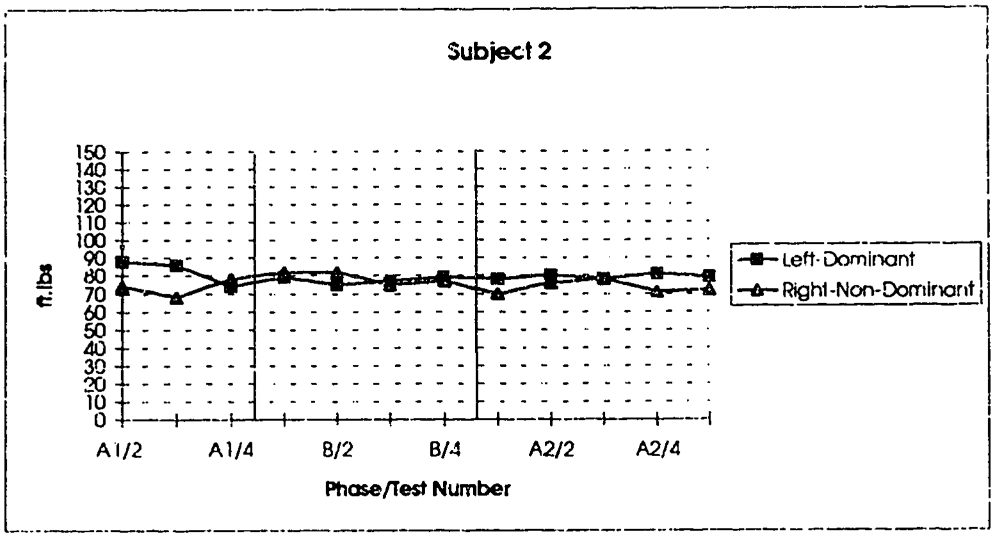


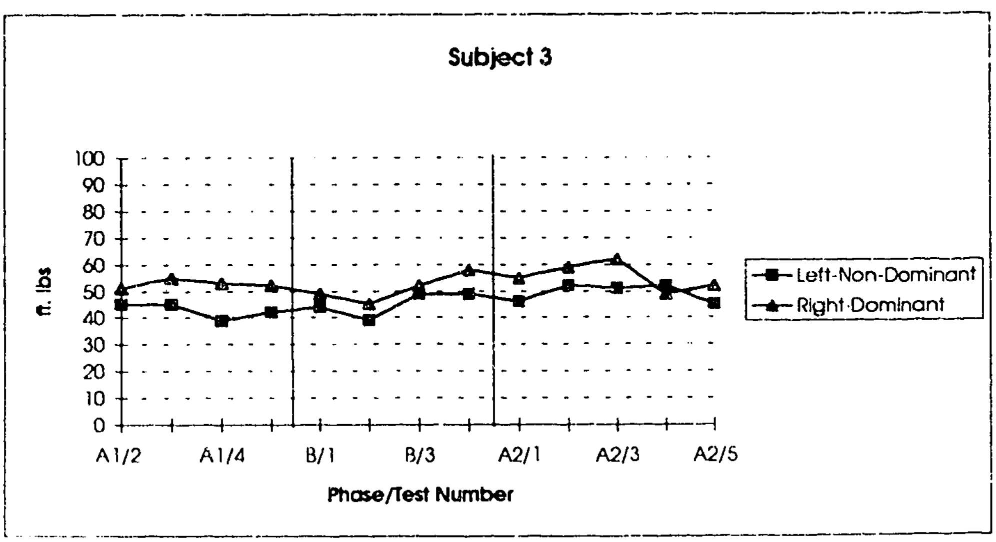


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Total Work Flexion 0.52 rad·sec⁻¹

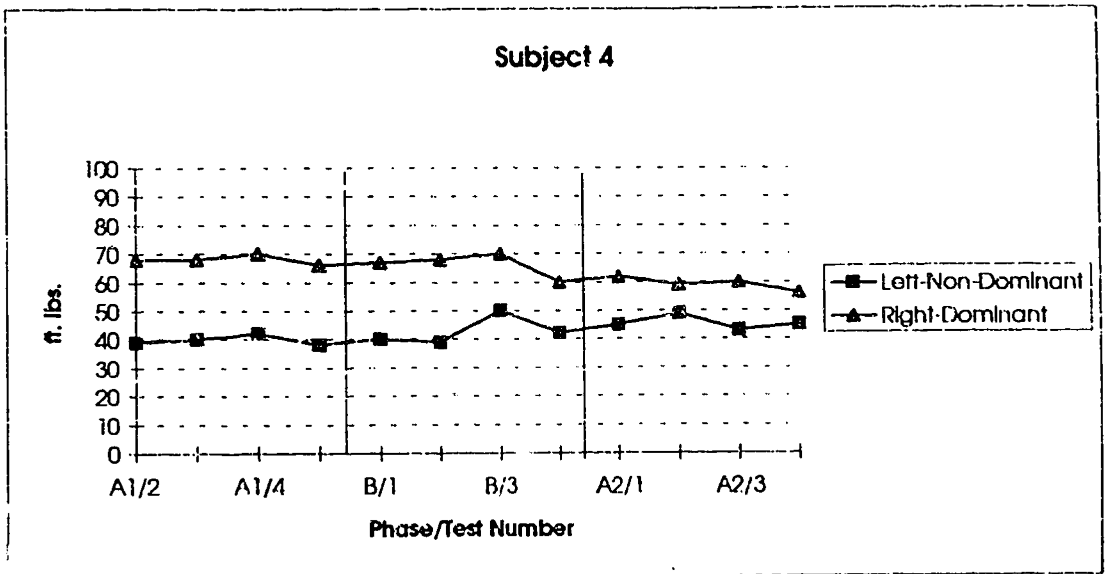


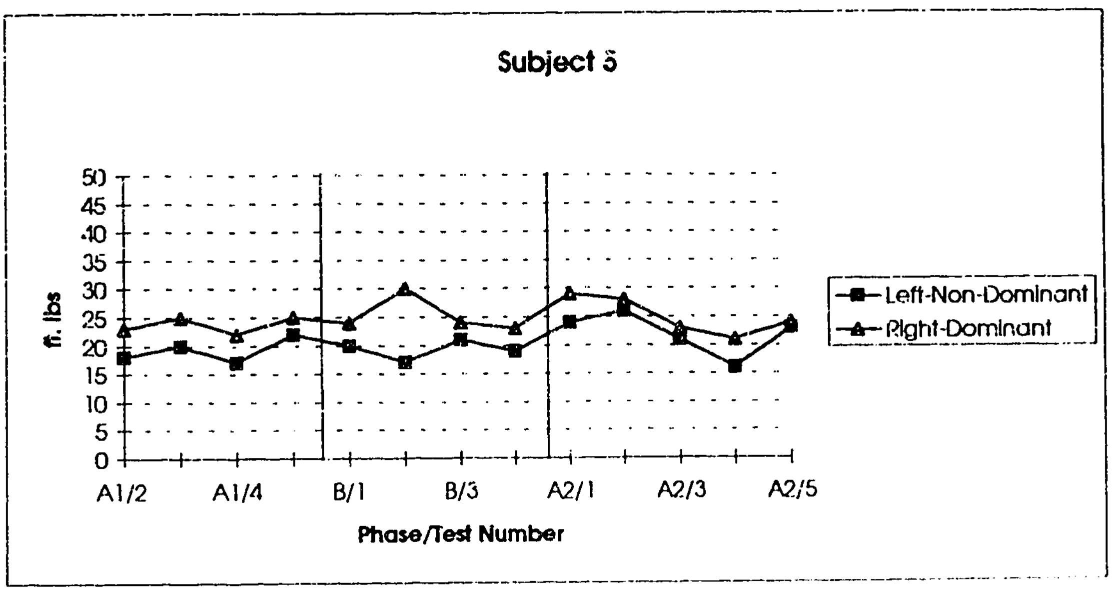




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

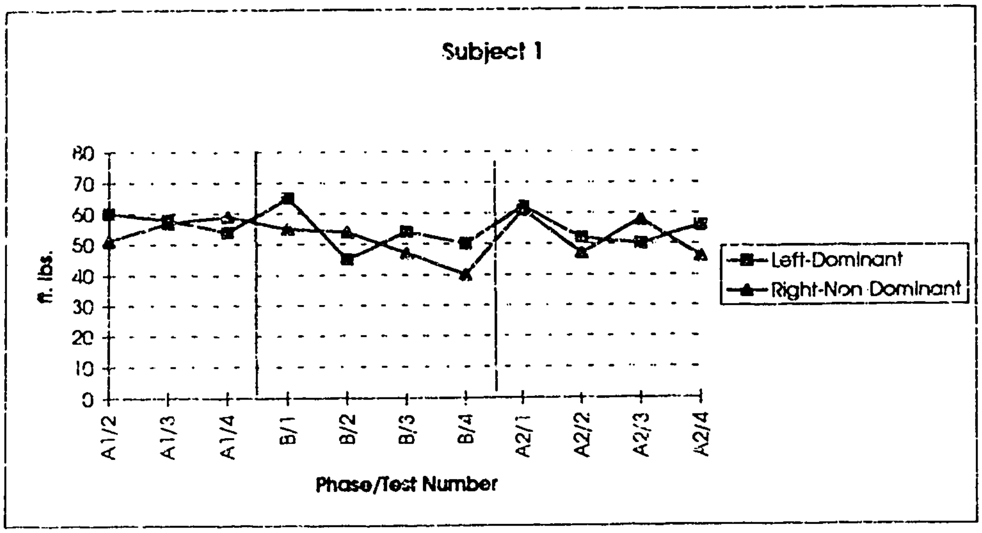
Total Work Flexion 0.52 rad·sec⁻¹

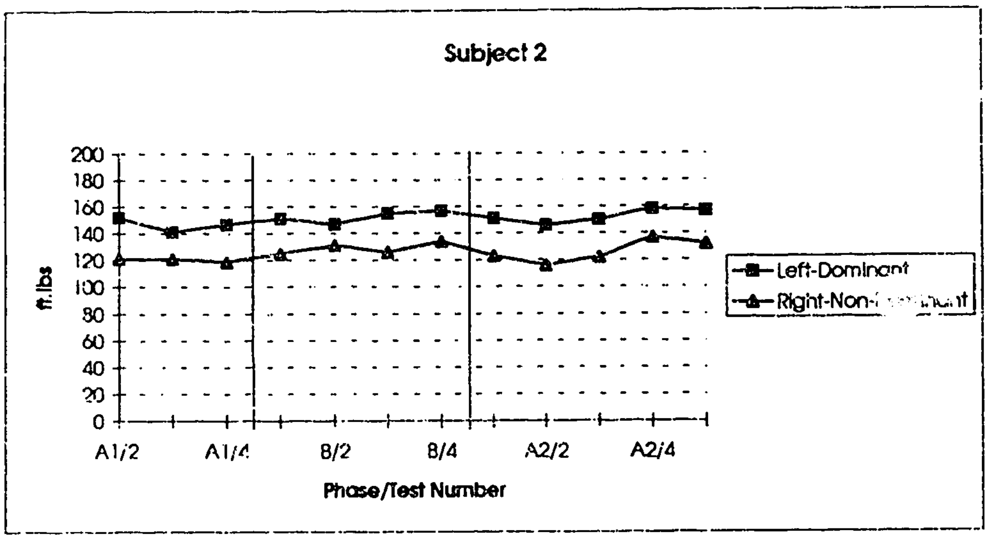


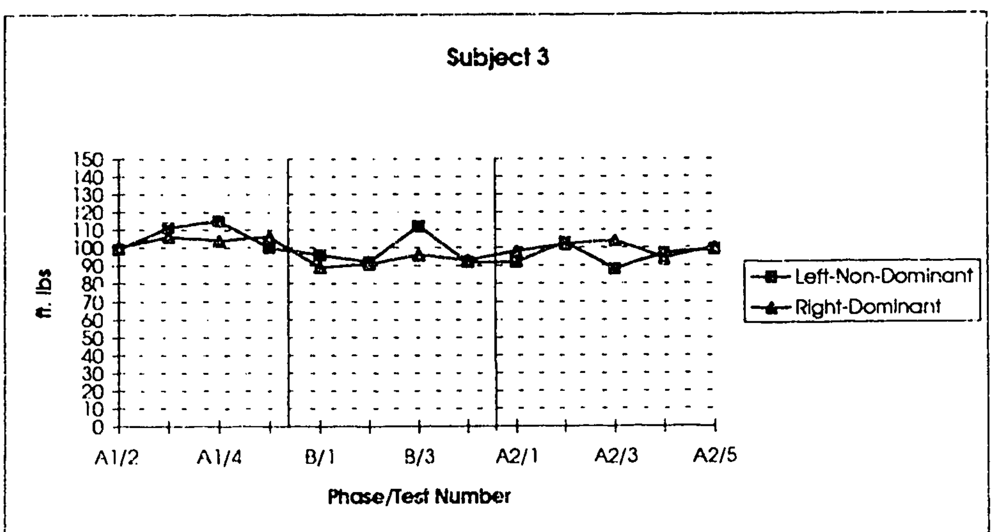


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Total Work Extension 0.52 rad·sec⁻¹

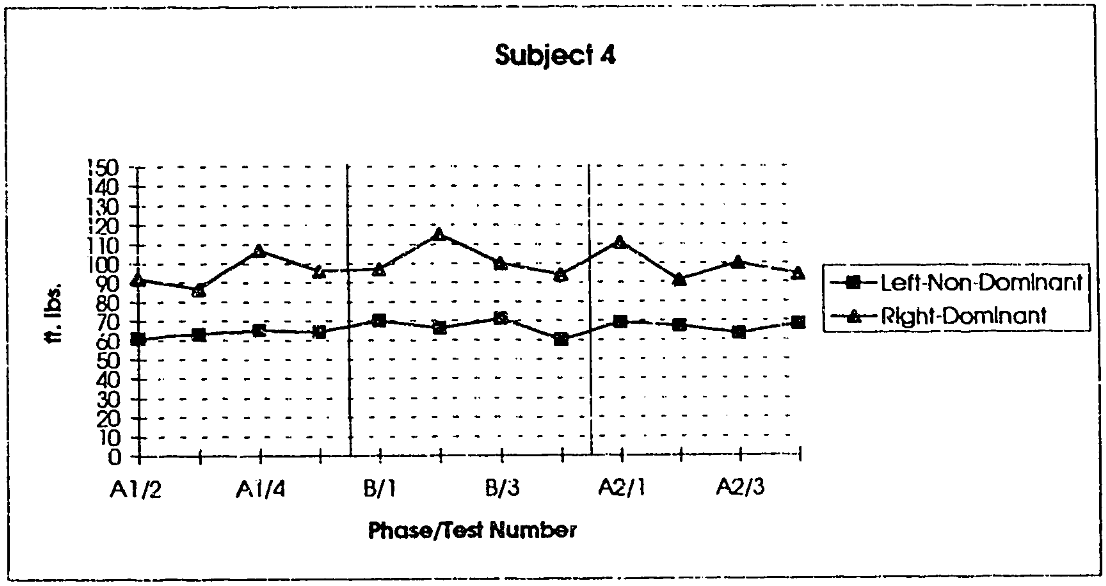


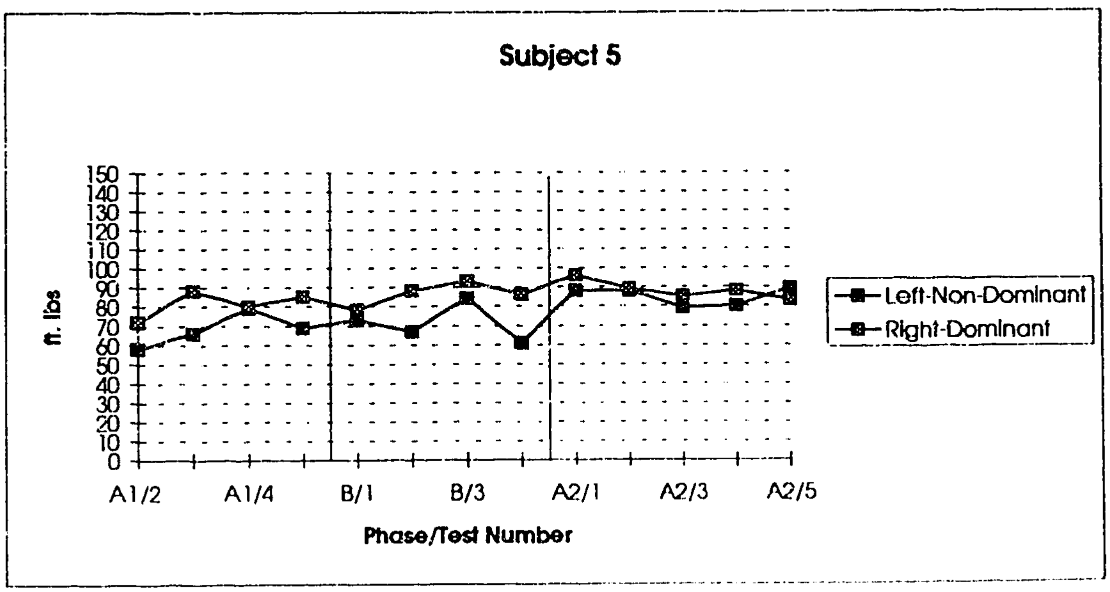




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

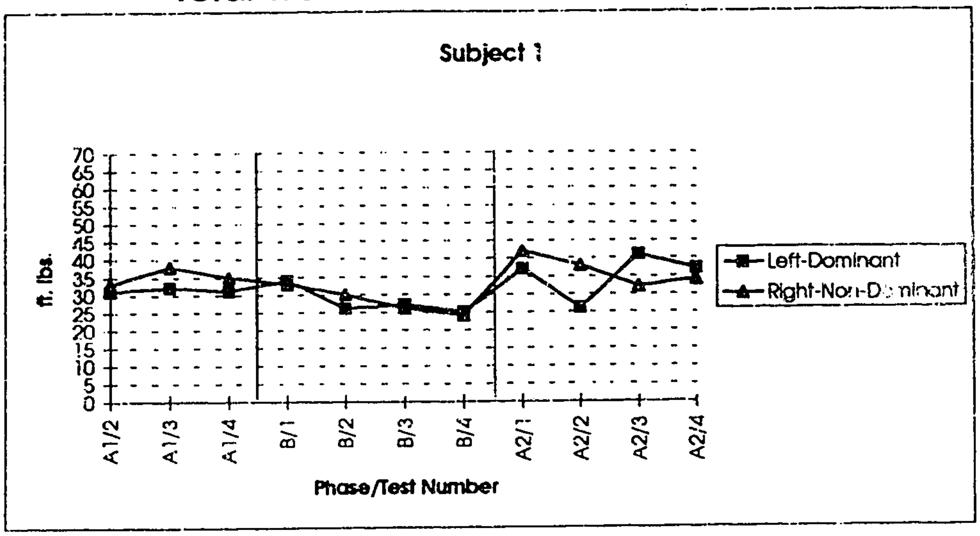
Total Work Extension 0.52 rad·sec^{-1}

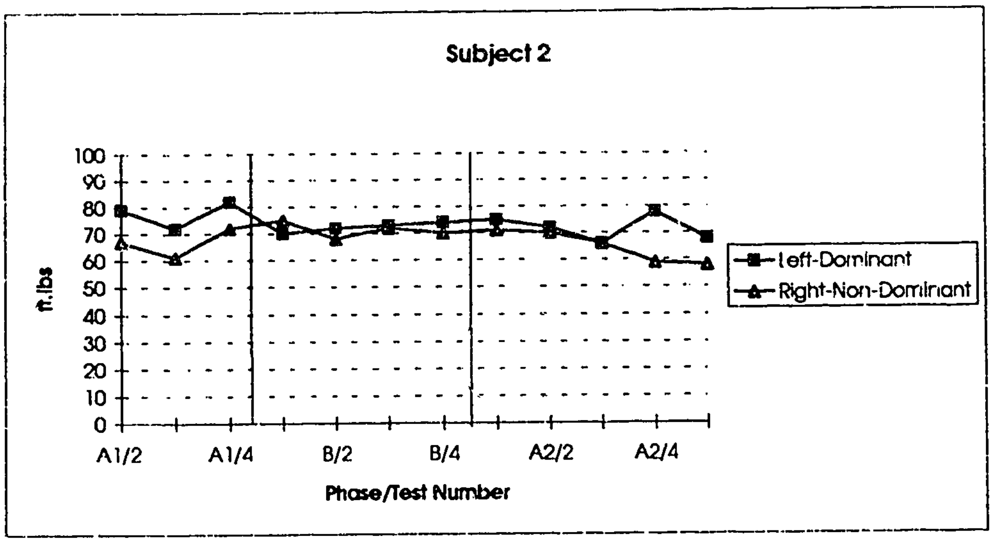


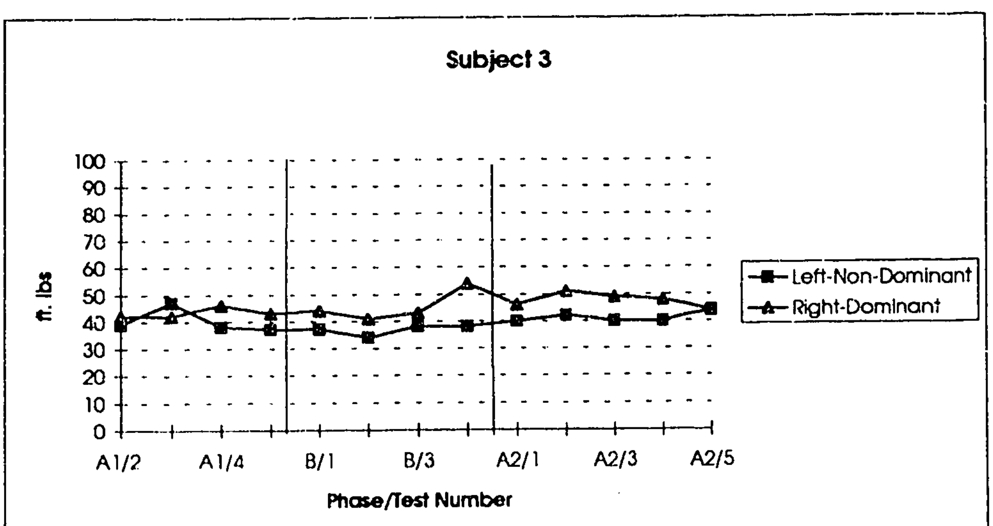


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Total Work Flexion 1.05 rad/sec⁻¹

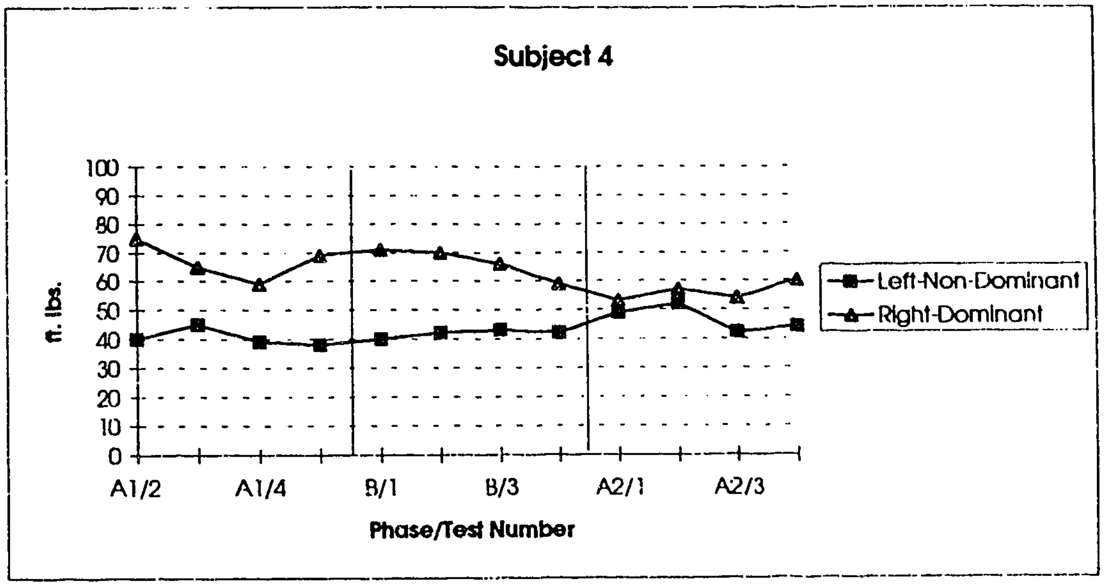


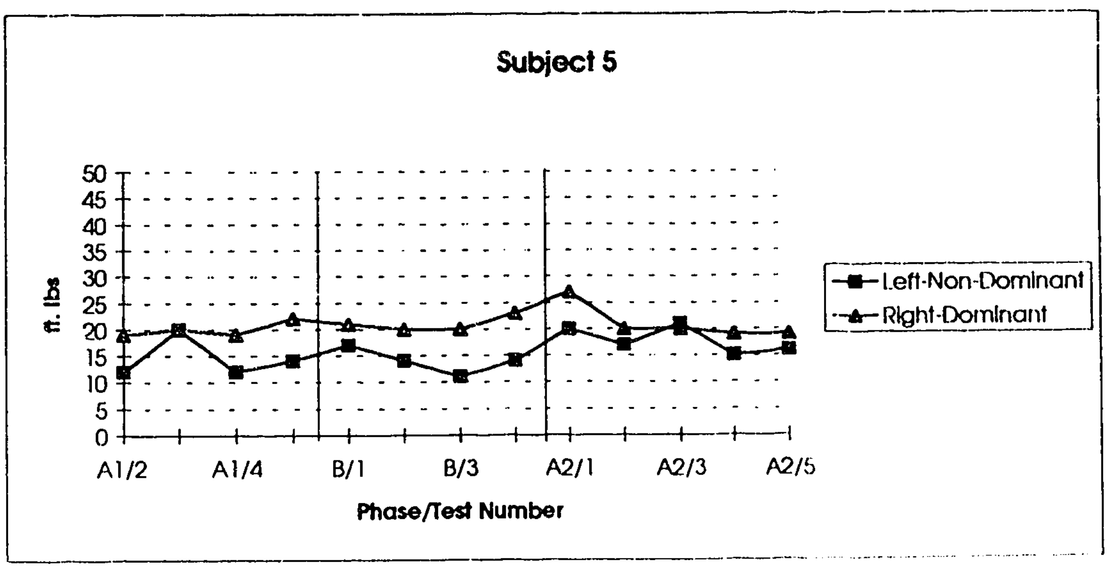




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

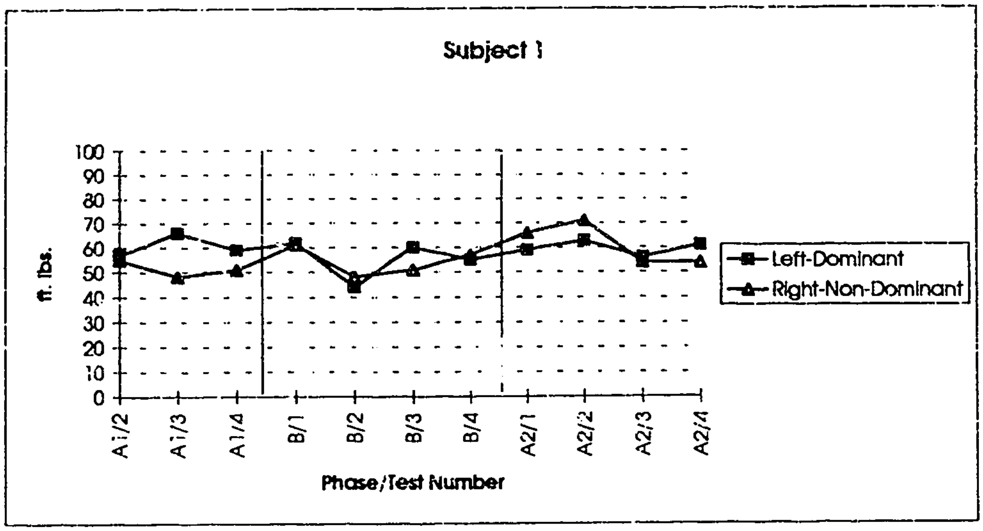
Total Work Flexion 1.05 $rad \cdot sec^{-1}$

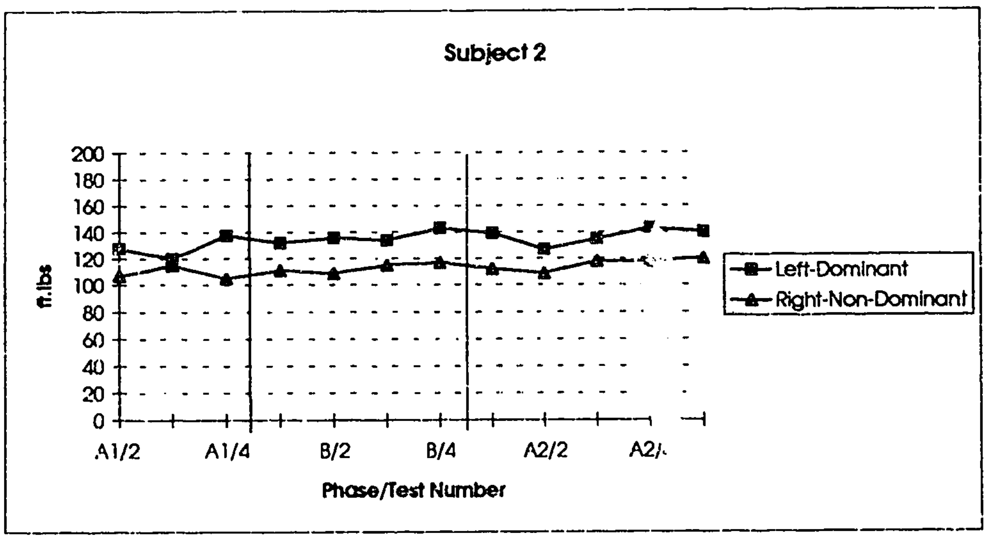


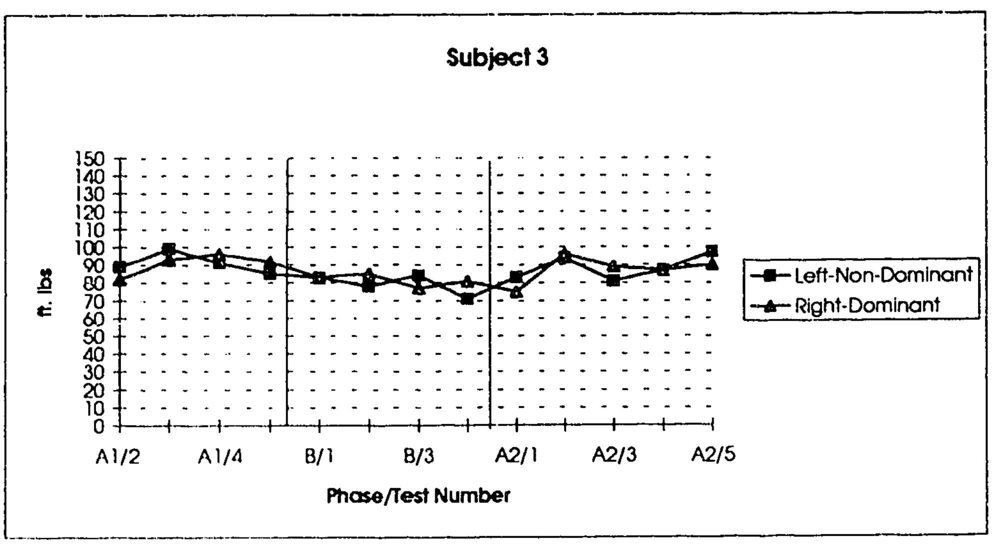


A1 - Baseline Phase   B - Intervention Phase   A2 - Withdrawal Phase

Total Work Extension 1.05 rad·sec⁻¹

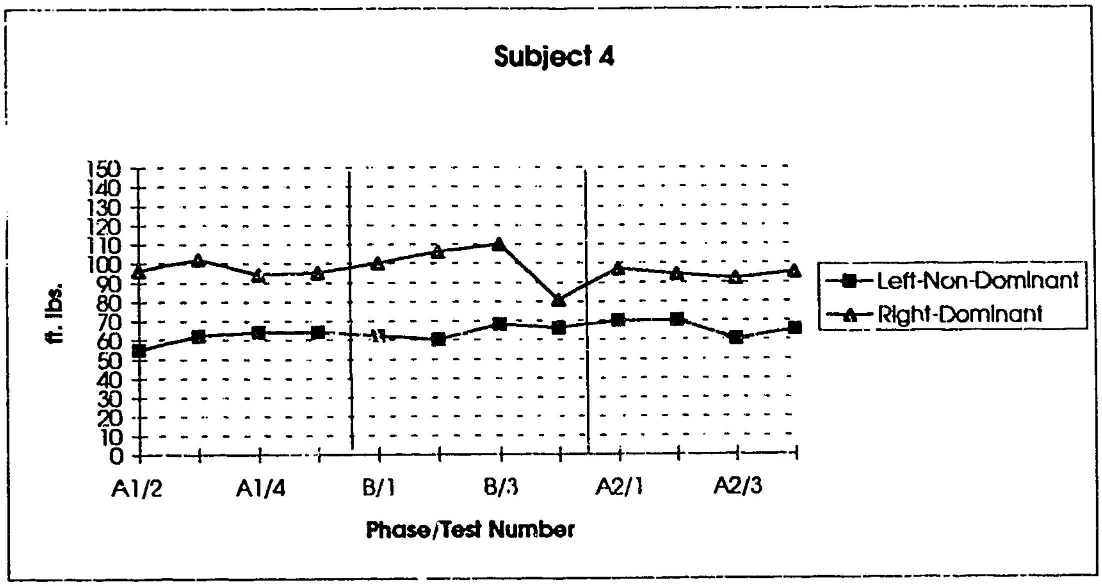


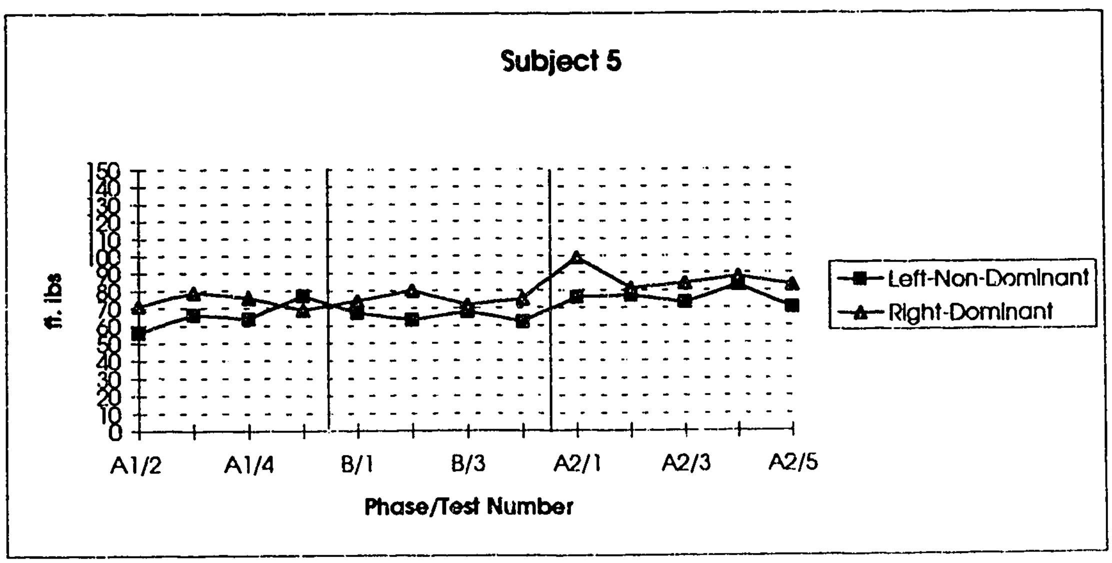




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

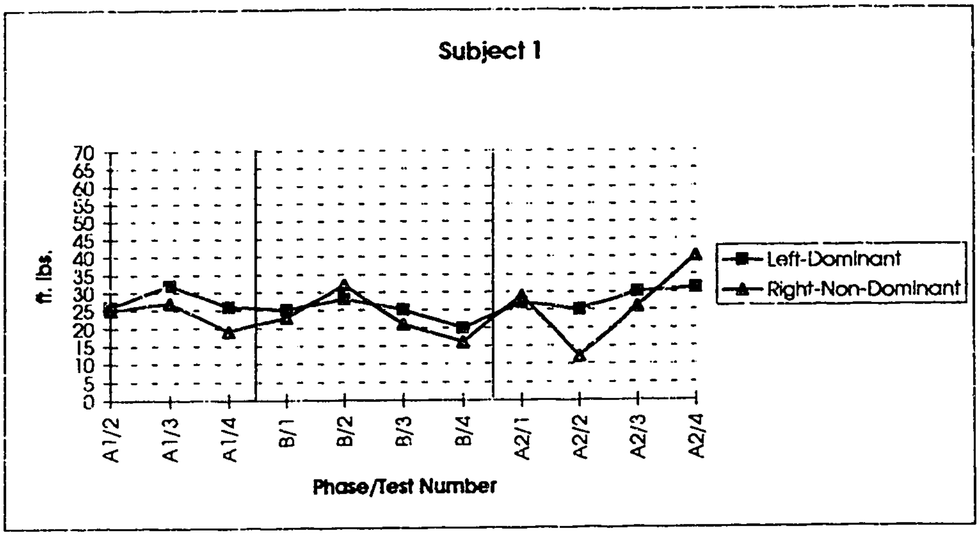
Total Work Extension 1.05 rad·sec⁻¹

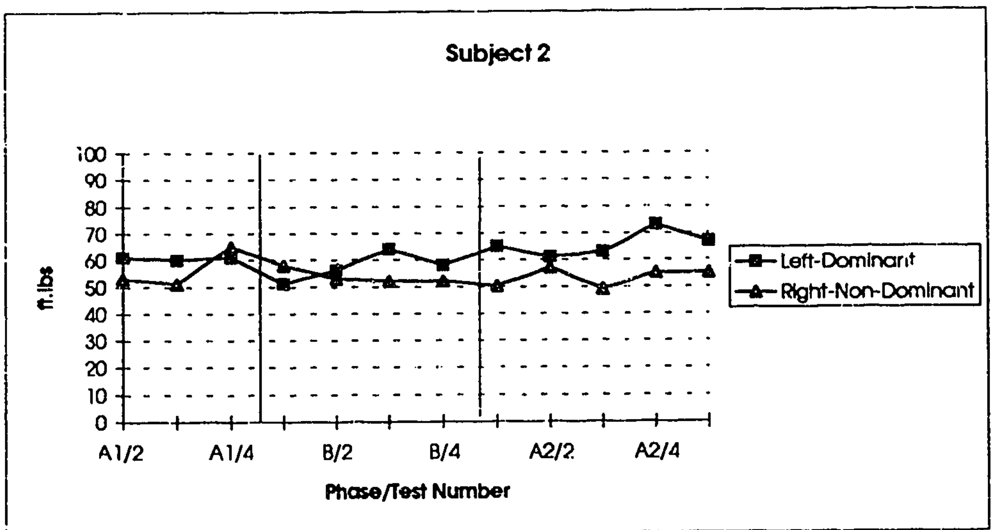


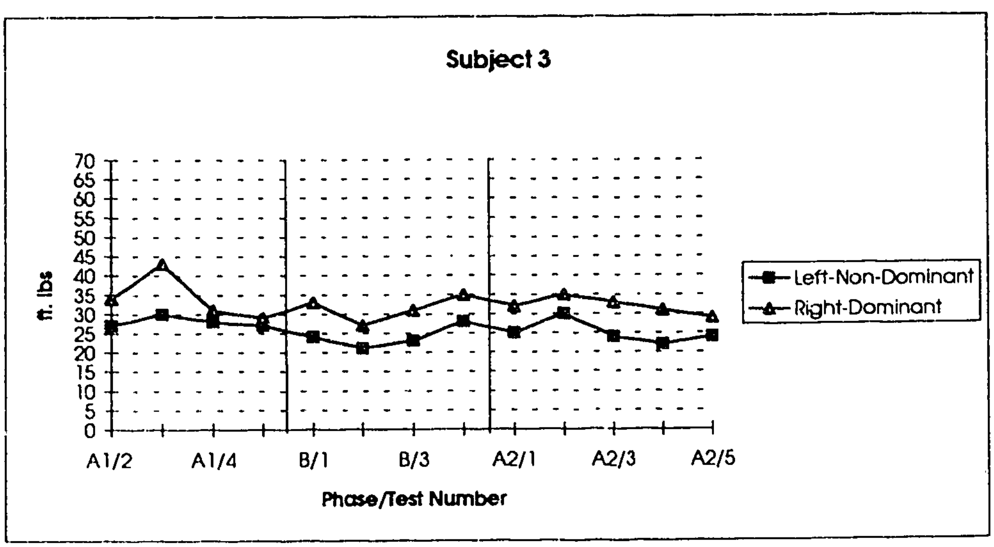


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Total Work Flexion 2.09 rad·sec⁻¹

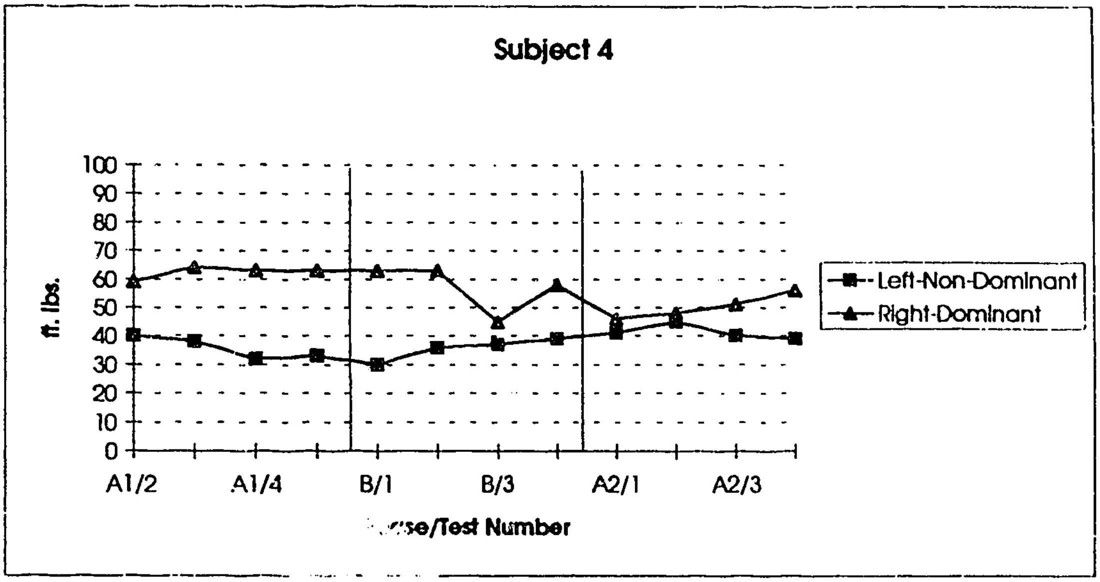


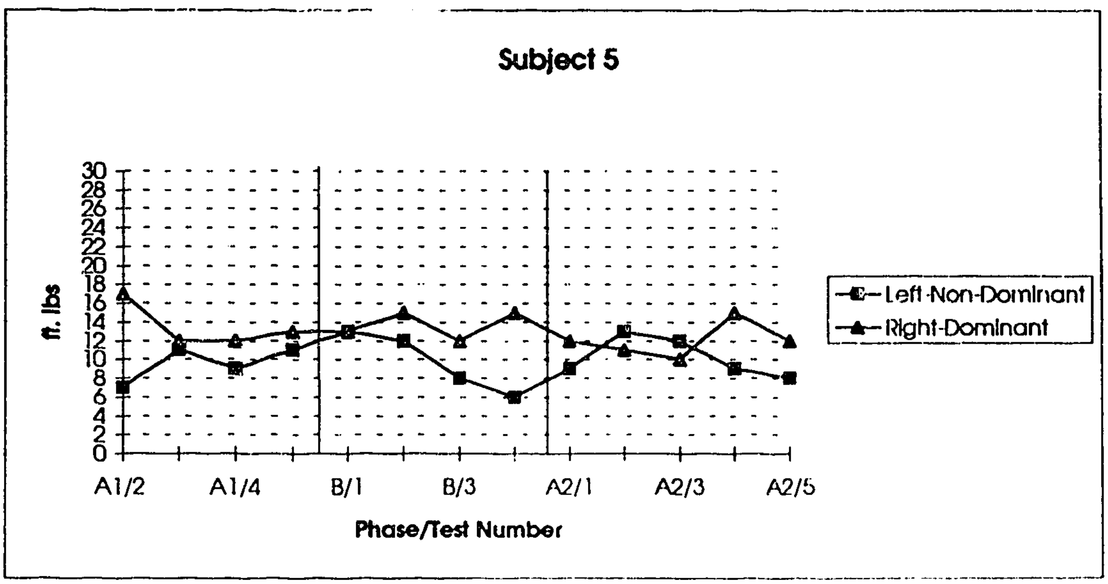




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

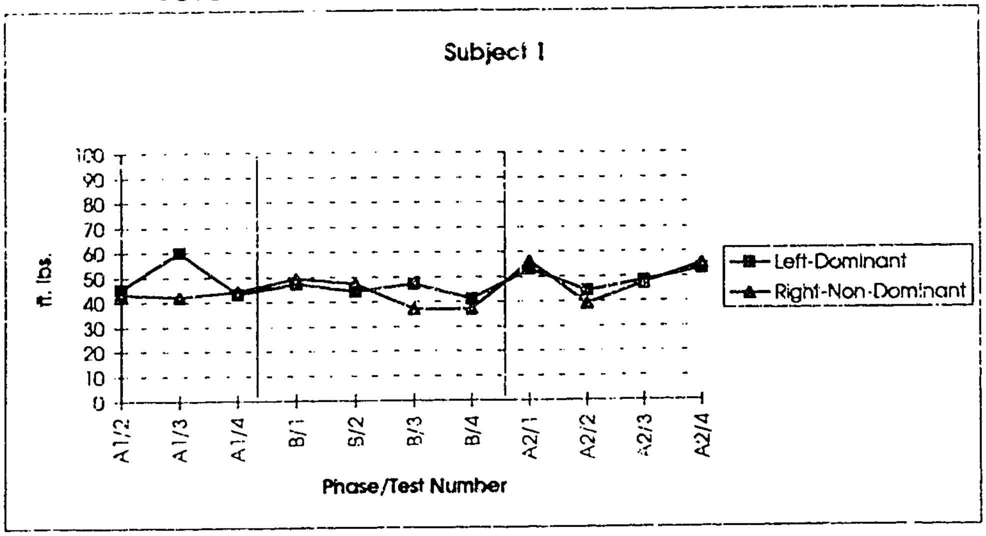
Total Work Flexion 2.09 rad·sec⁻¹

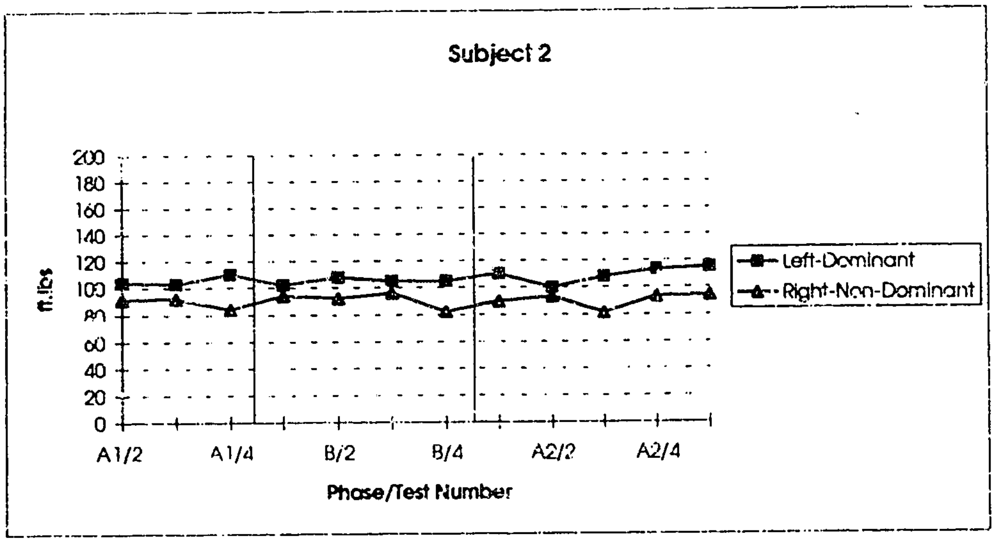


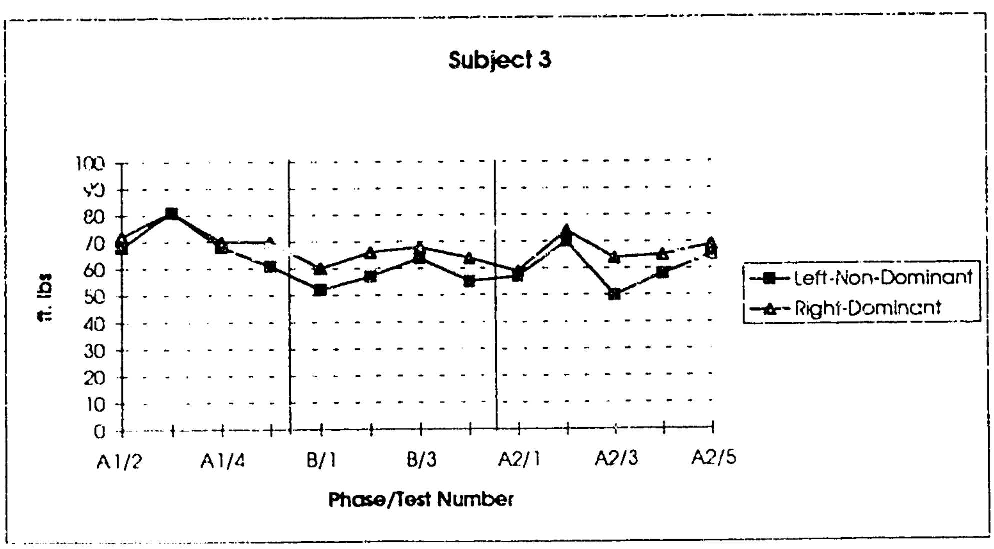


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Total Work Extension 2.09 rad·sec⁻¹

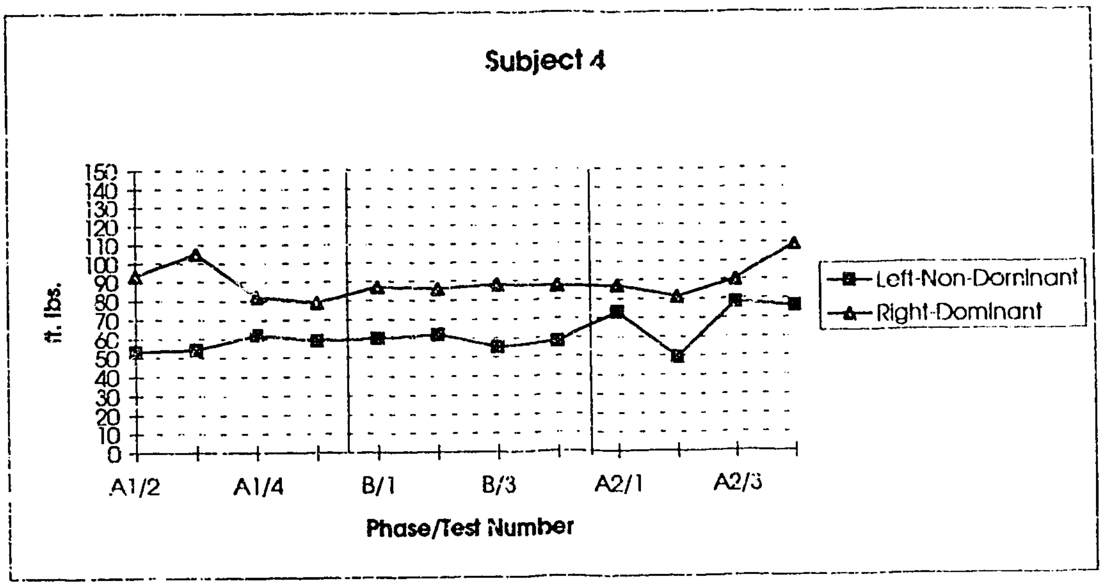


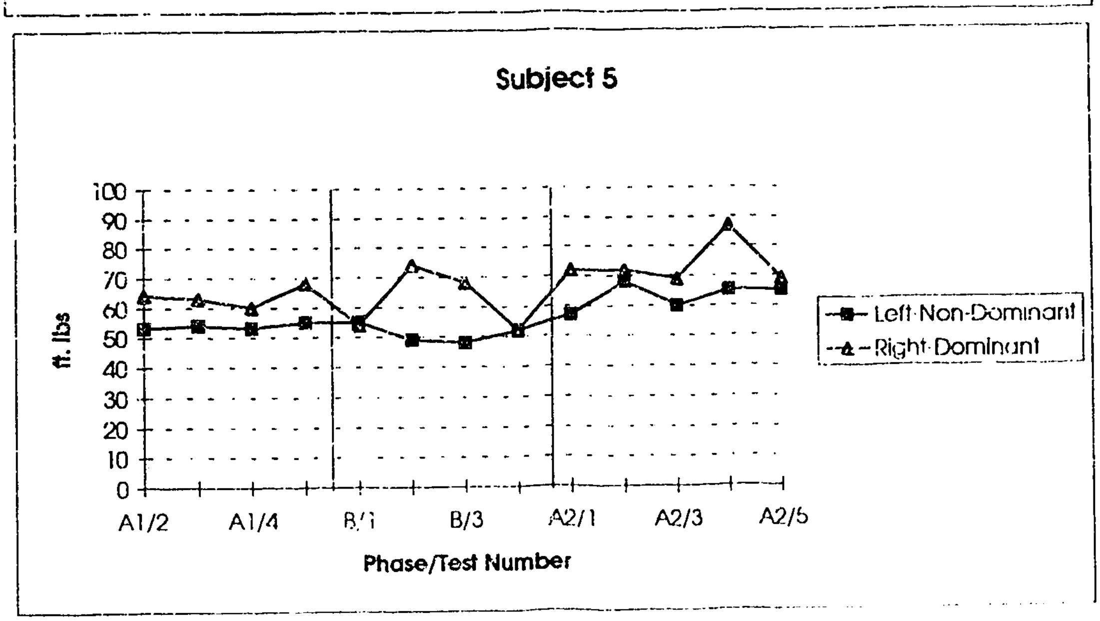




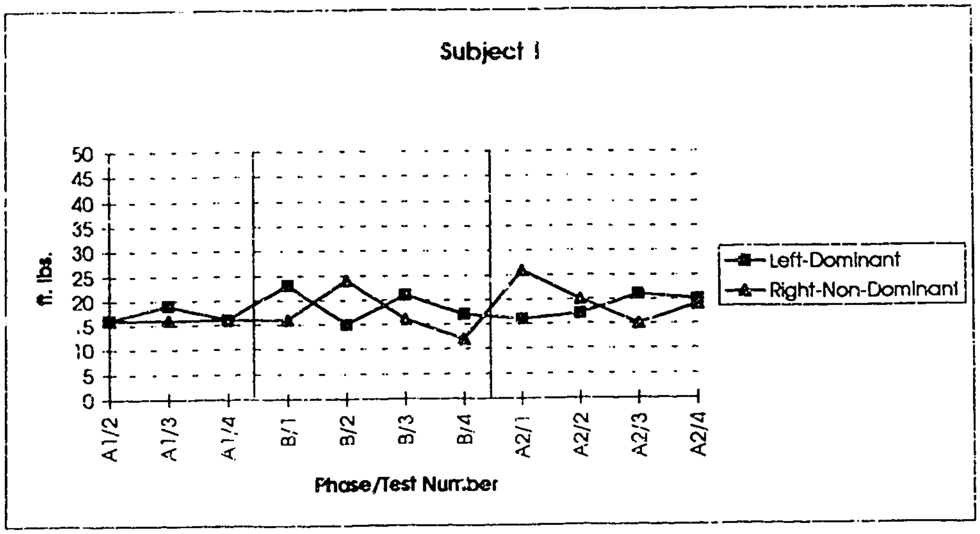
A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

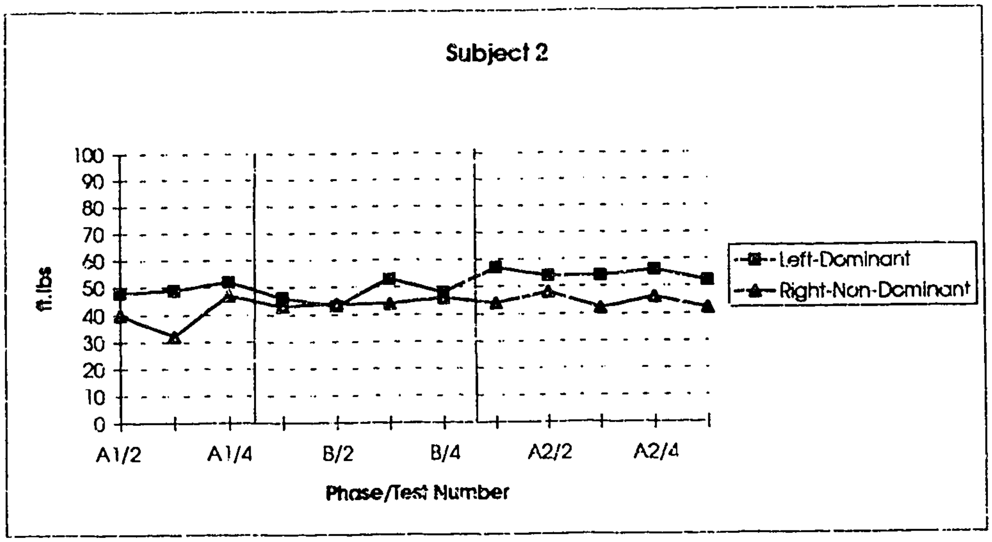
Total Work Extension 2.09 rad sec⁻¹

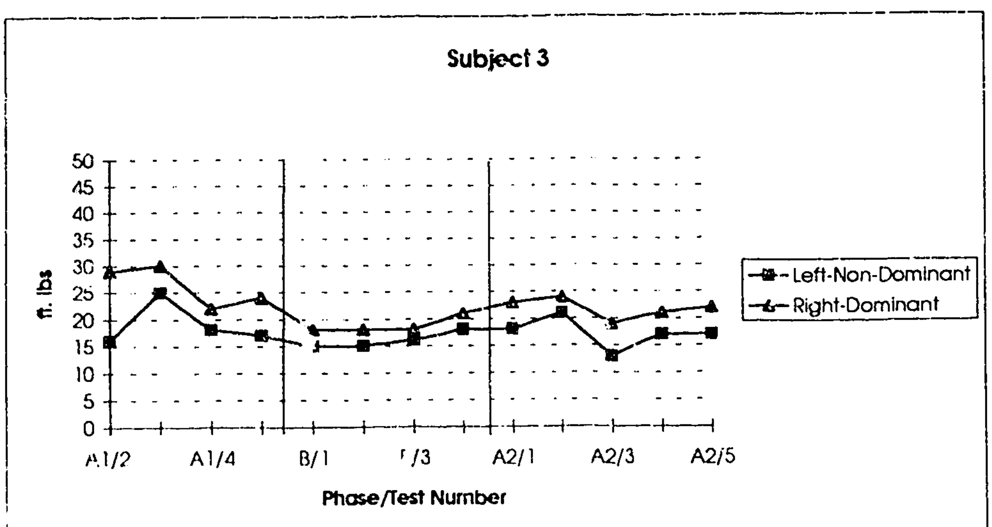




Total Work Flexion 3.1 • rad·sec⁻¹

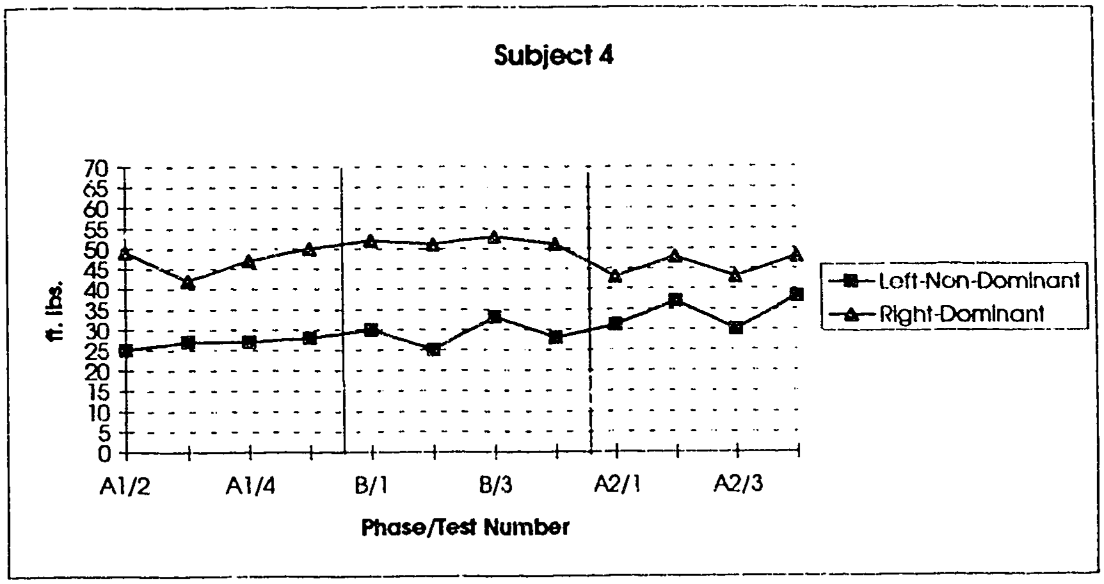


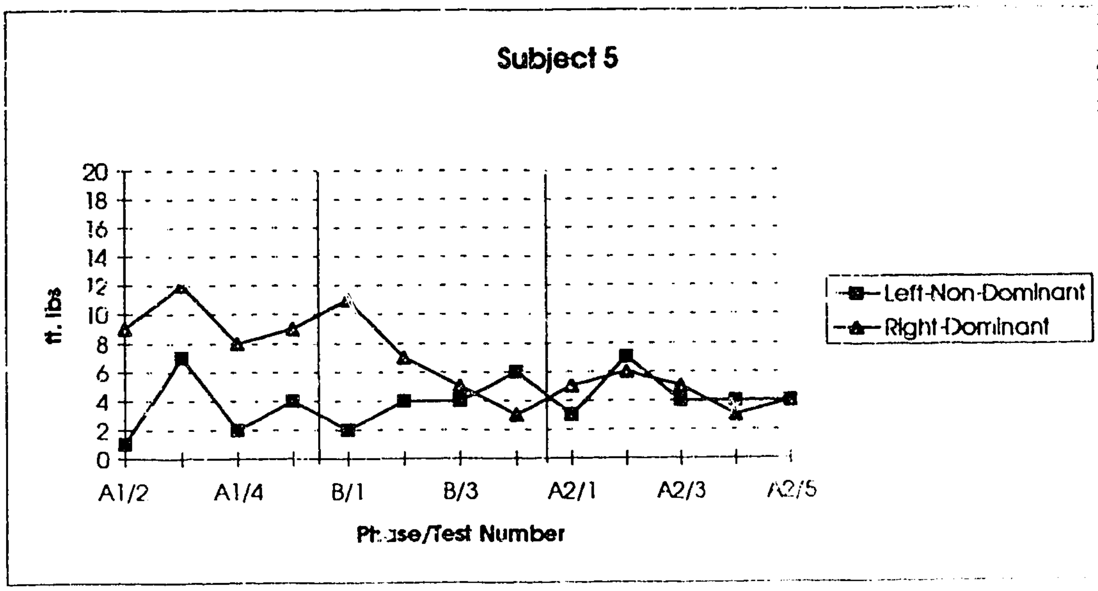




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

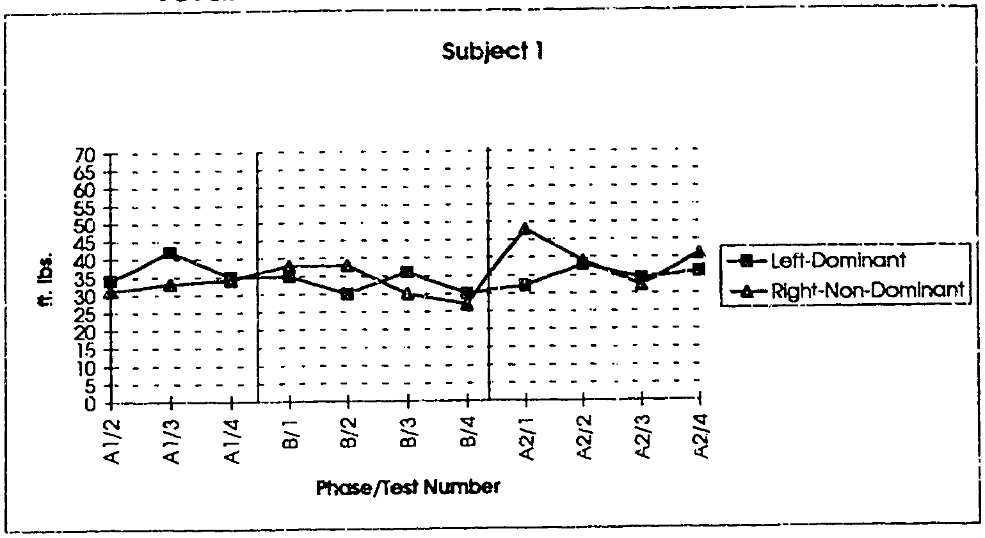
Total Work Flexion 3.14 rad·sec^{-1}

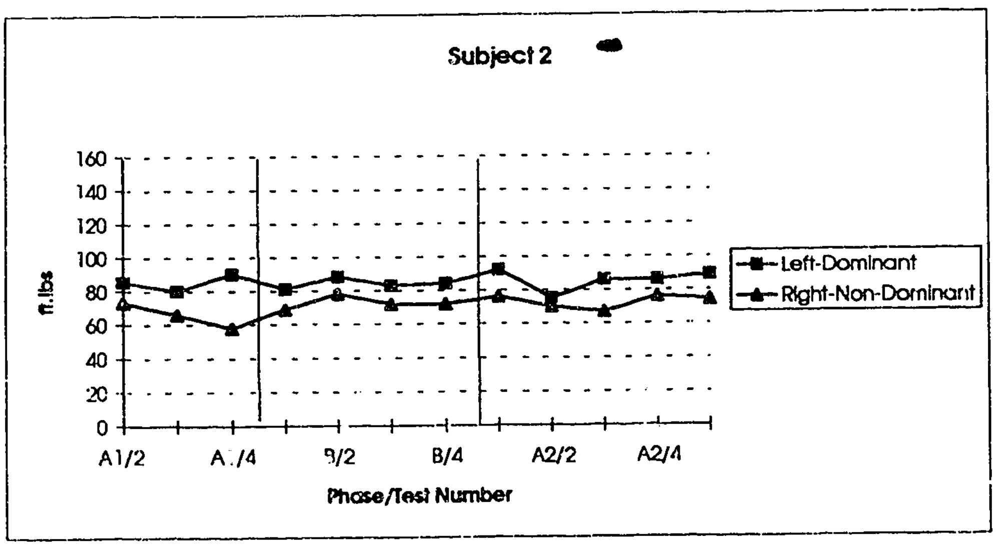


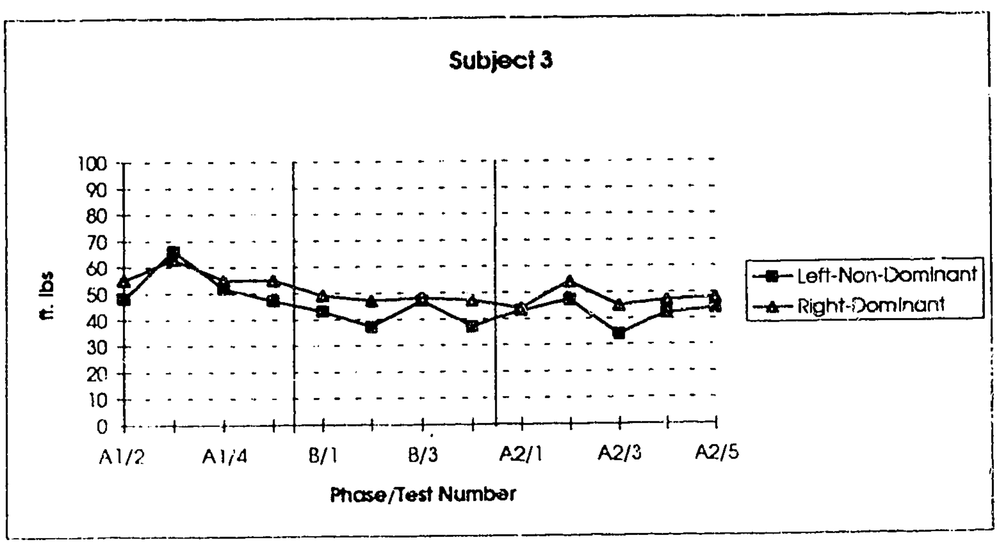


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Total Work Extension 3.14 $rad \cdot sec^{-1}$

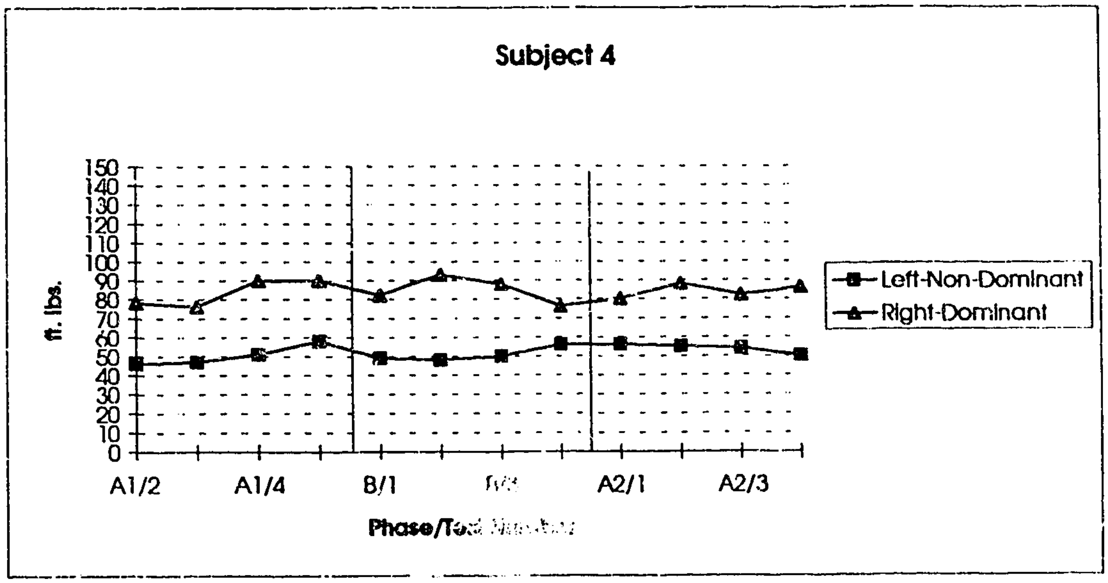


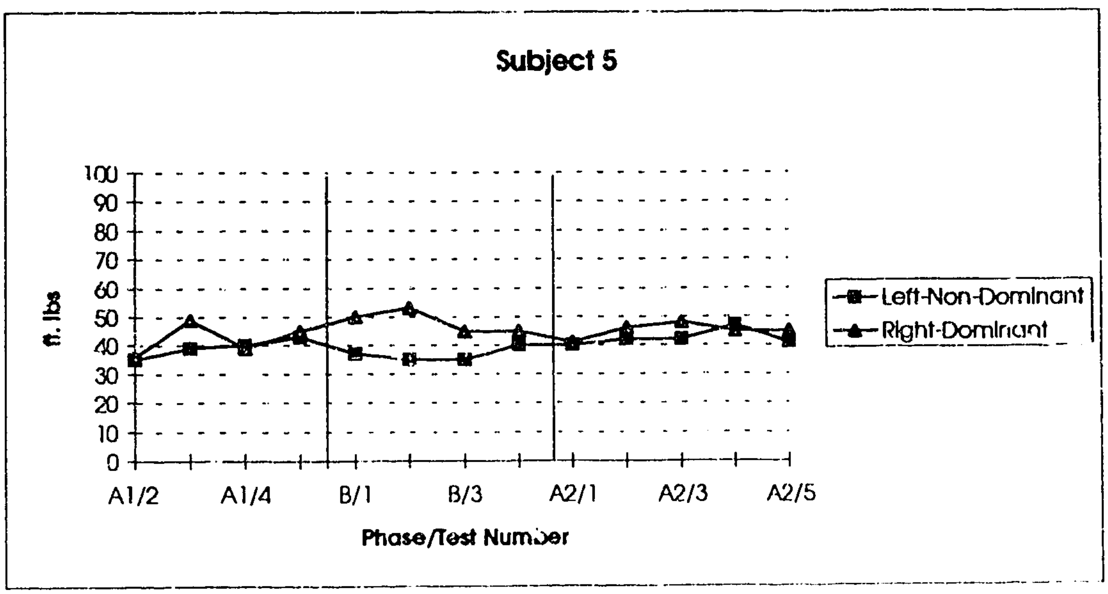




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

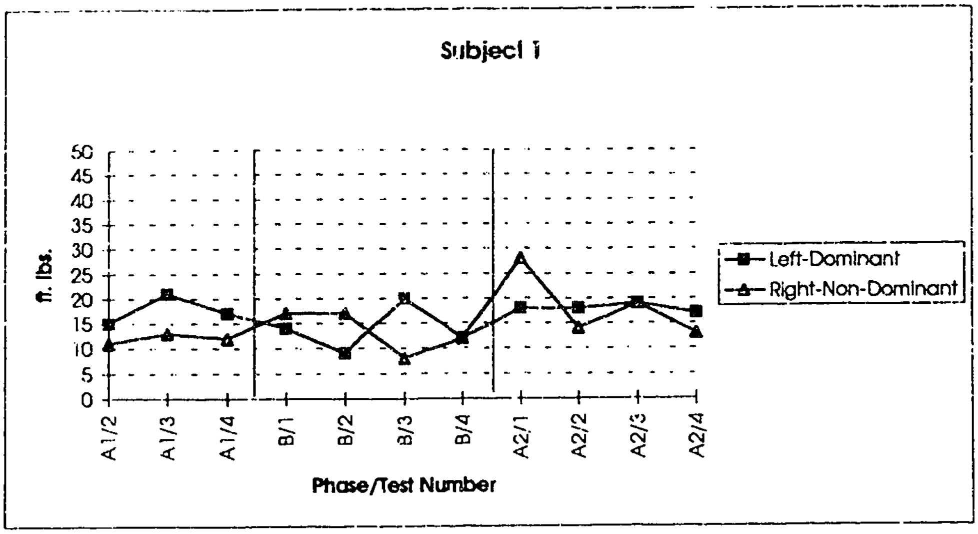
Total Work Extension 3.14 rad·sec⁻¹

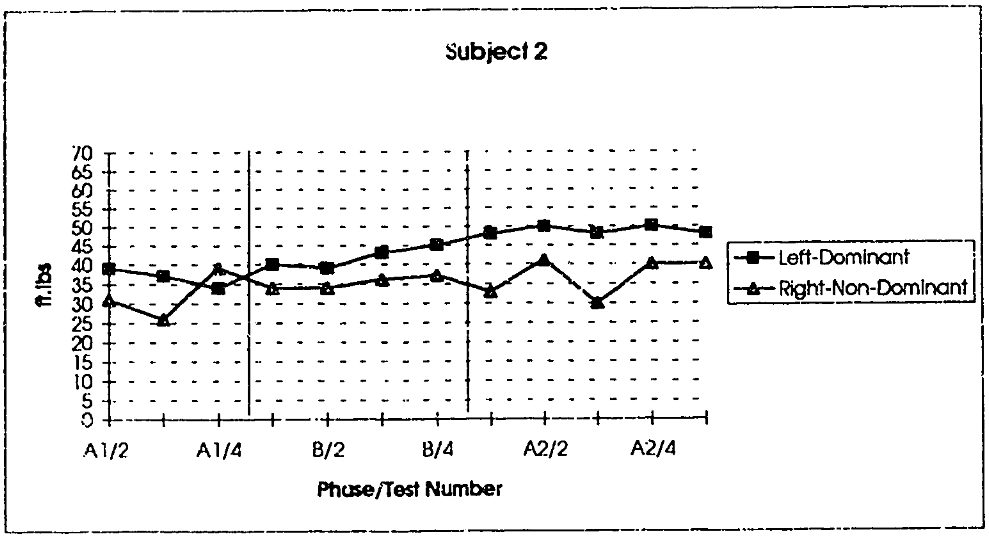


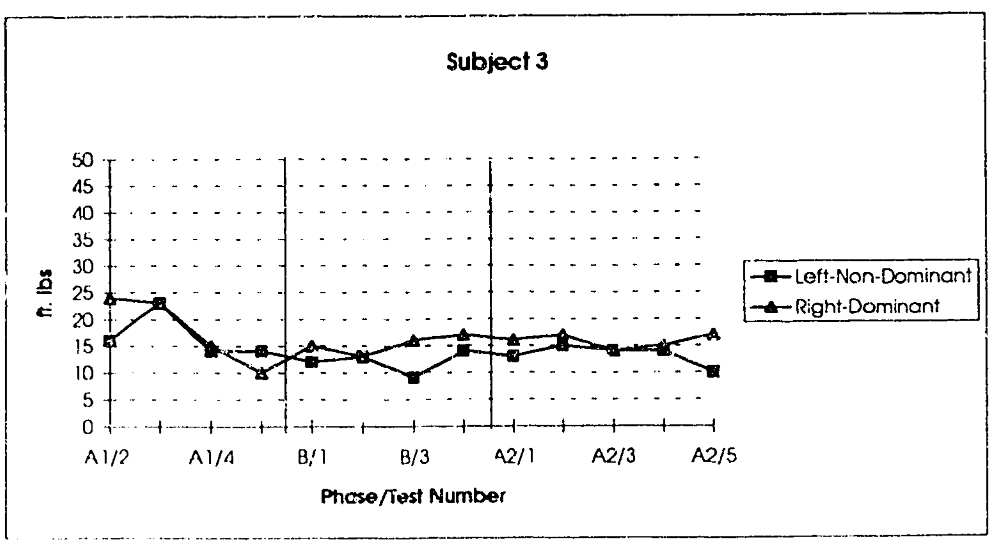


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Total Work Flexion 4.19 rad·sec^{-1}

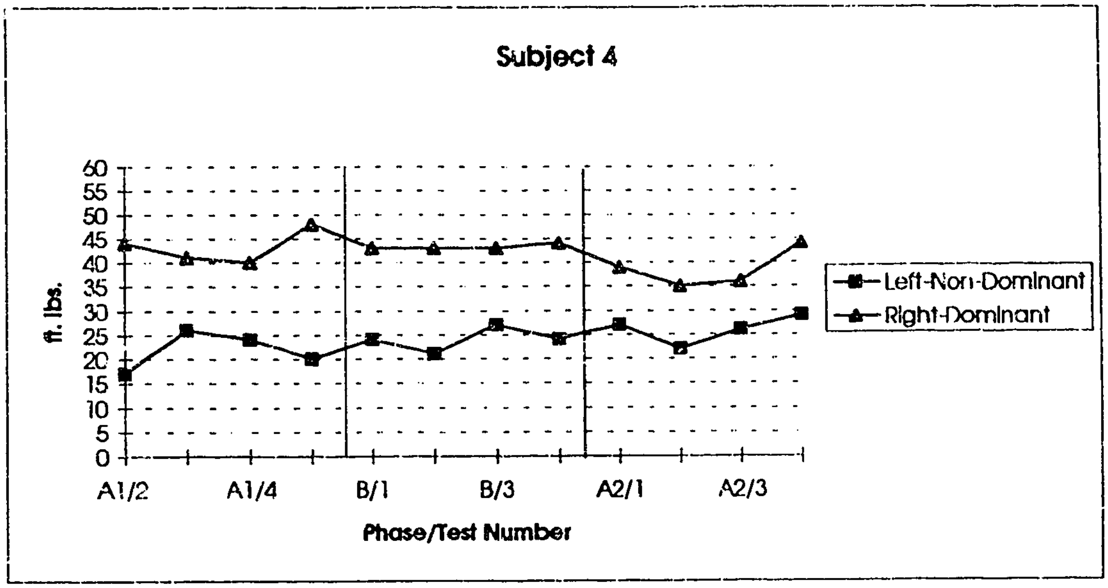


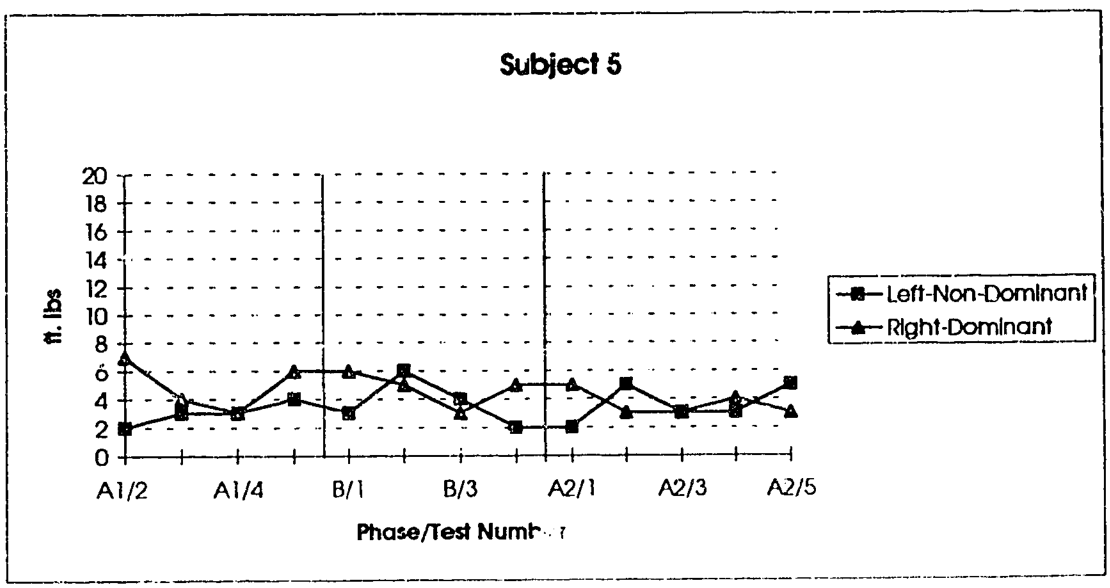




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

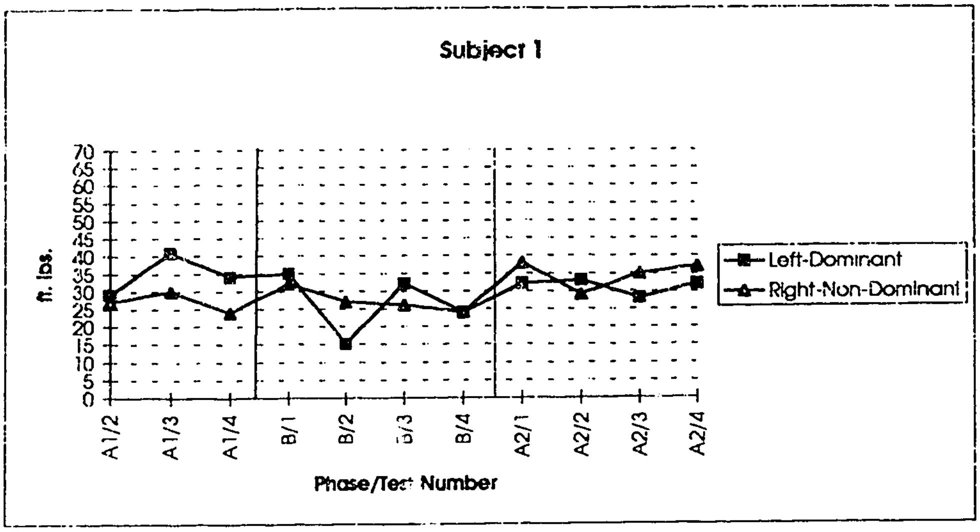
Total Work Flexion 4.19 rad·sec⁻¹

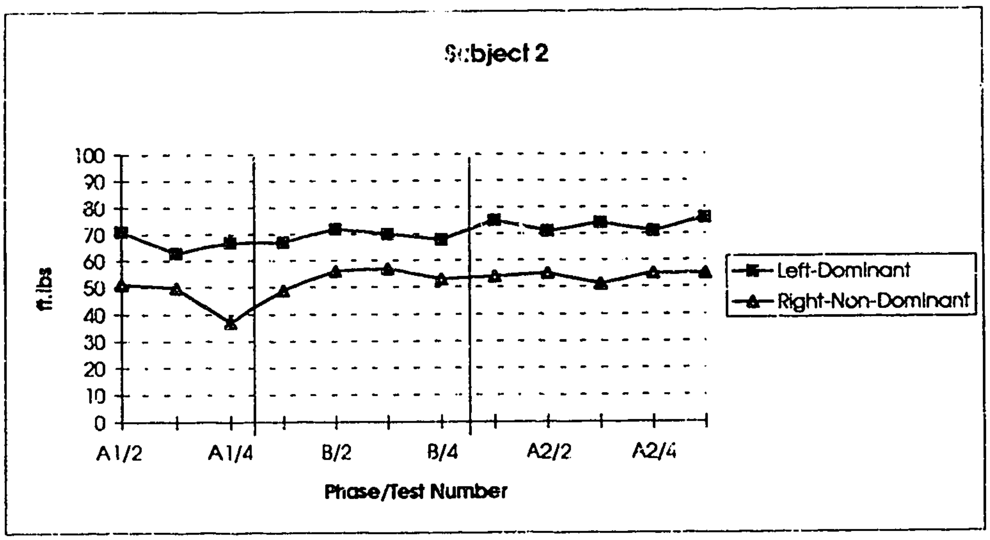


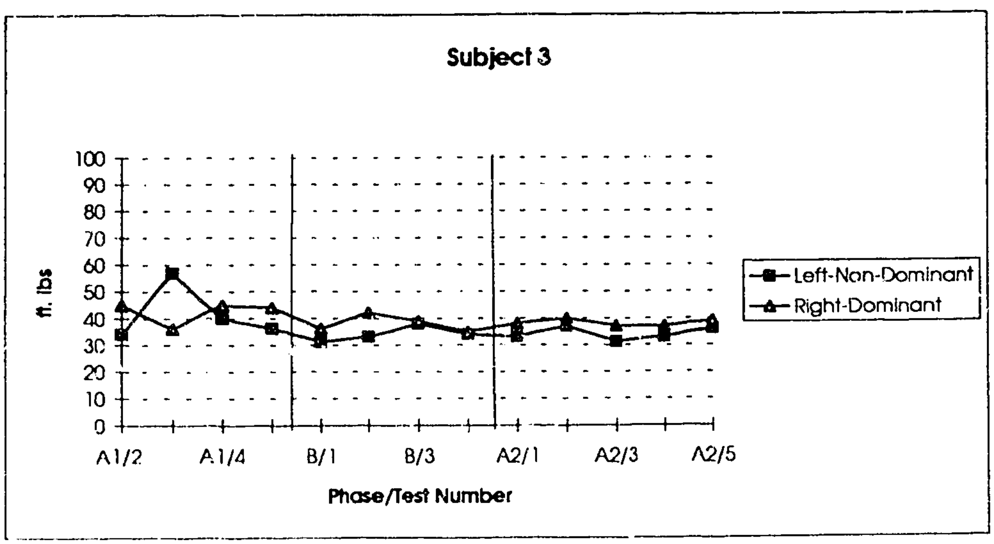


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Total Work Extension 4.19 $rad \cdot sec^{-1}$

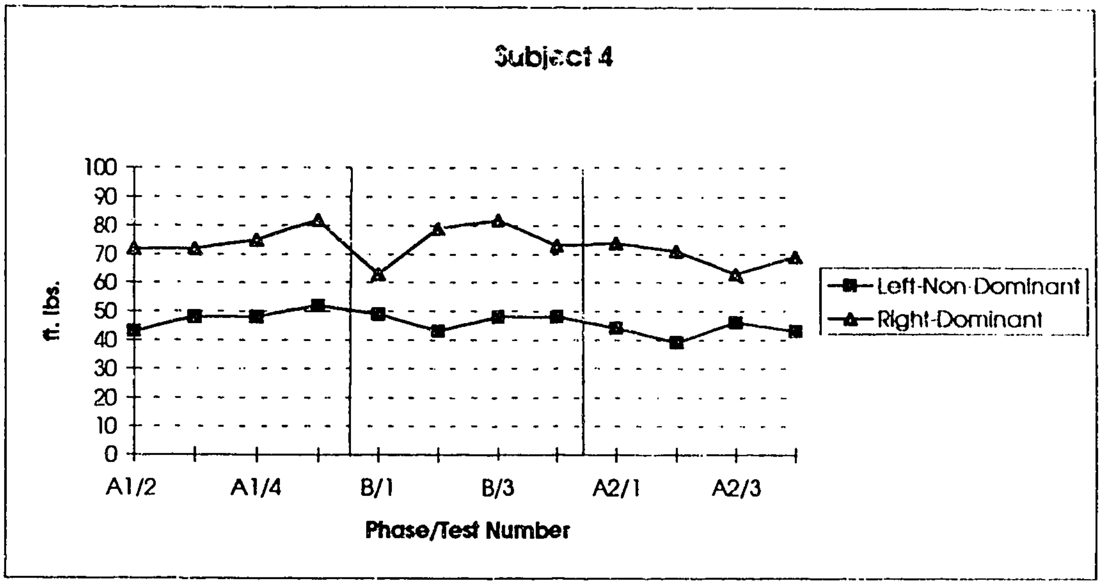


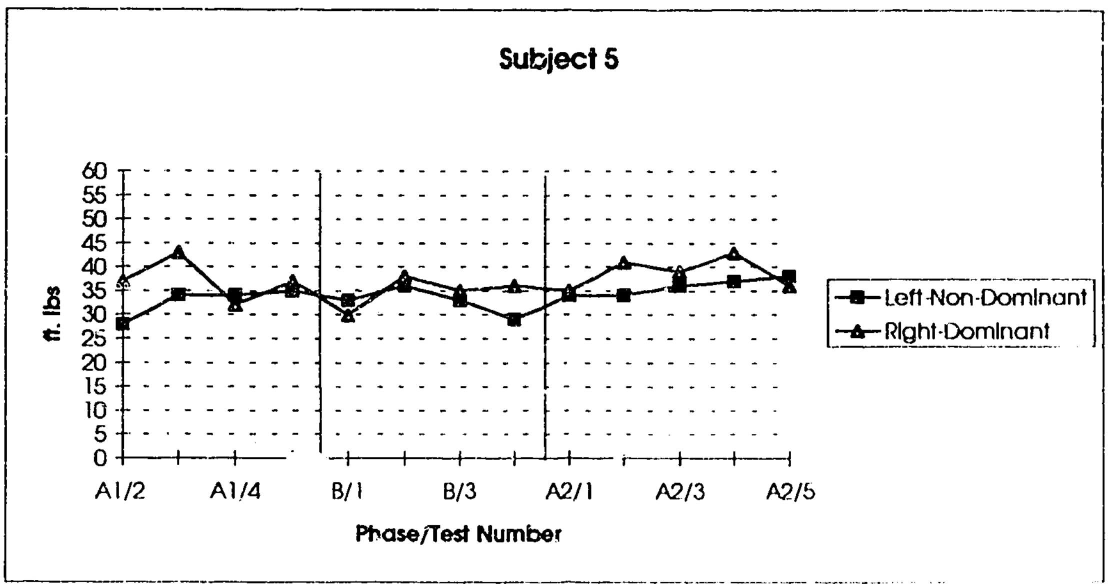




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

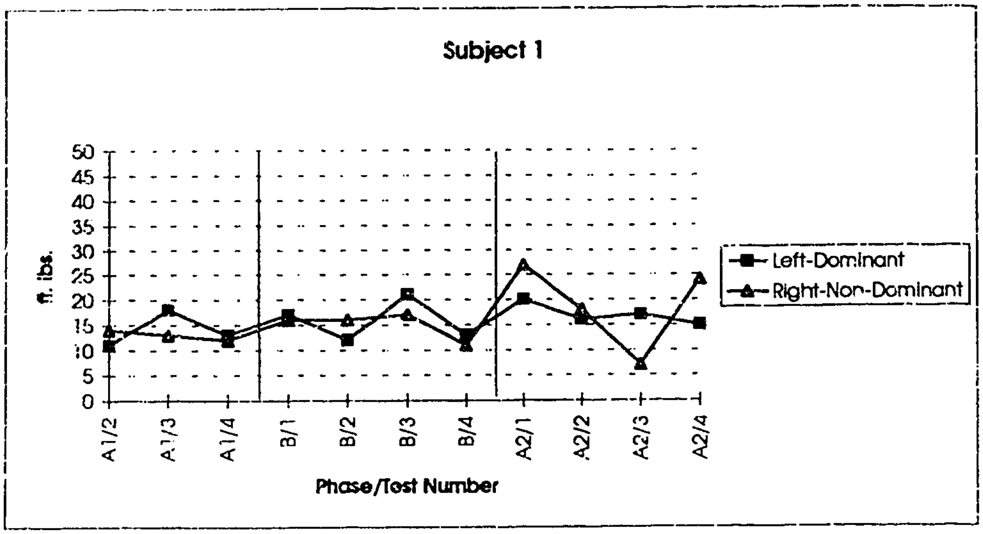
Total Work Extension 4.19 rad·sec^{-1}

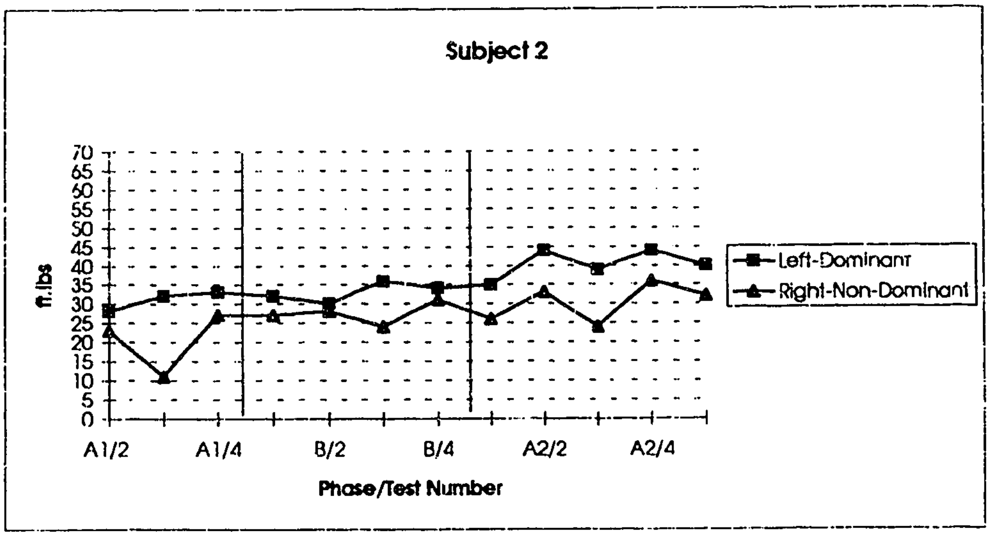


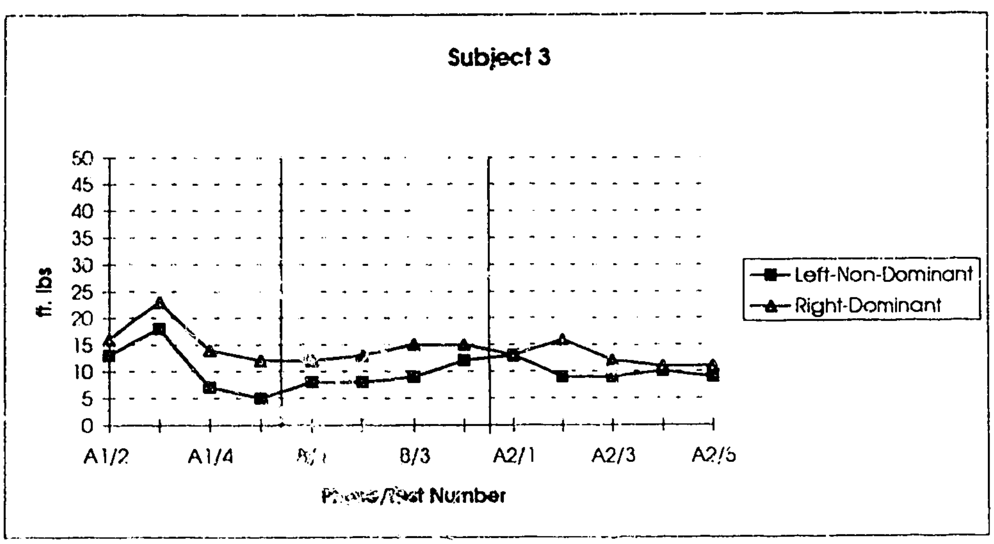


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Total Work Flexion 5.24 rad·sec⁻¹

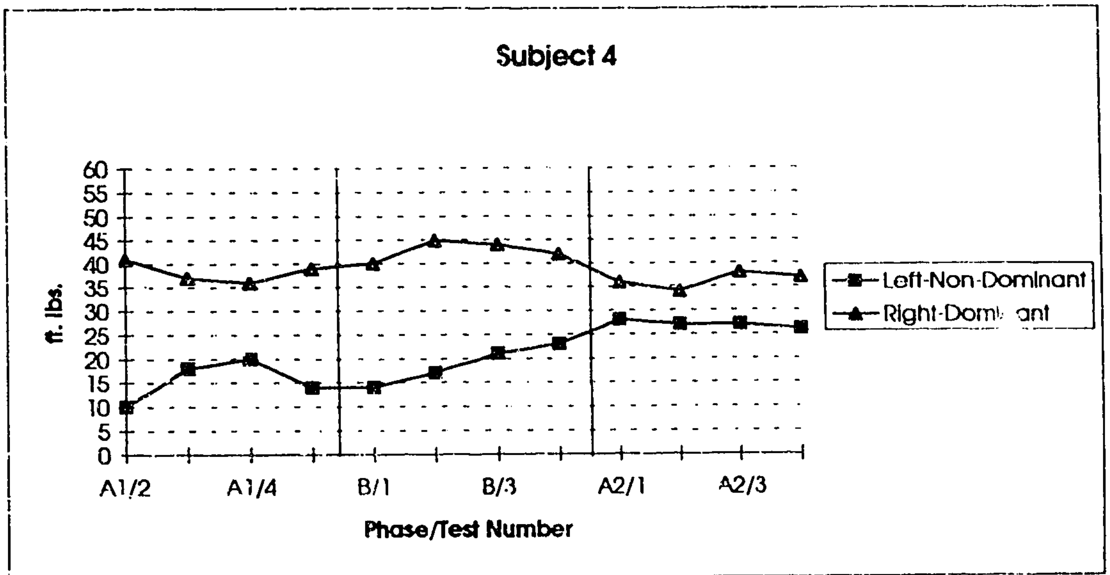


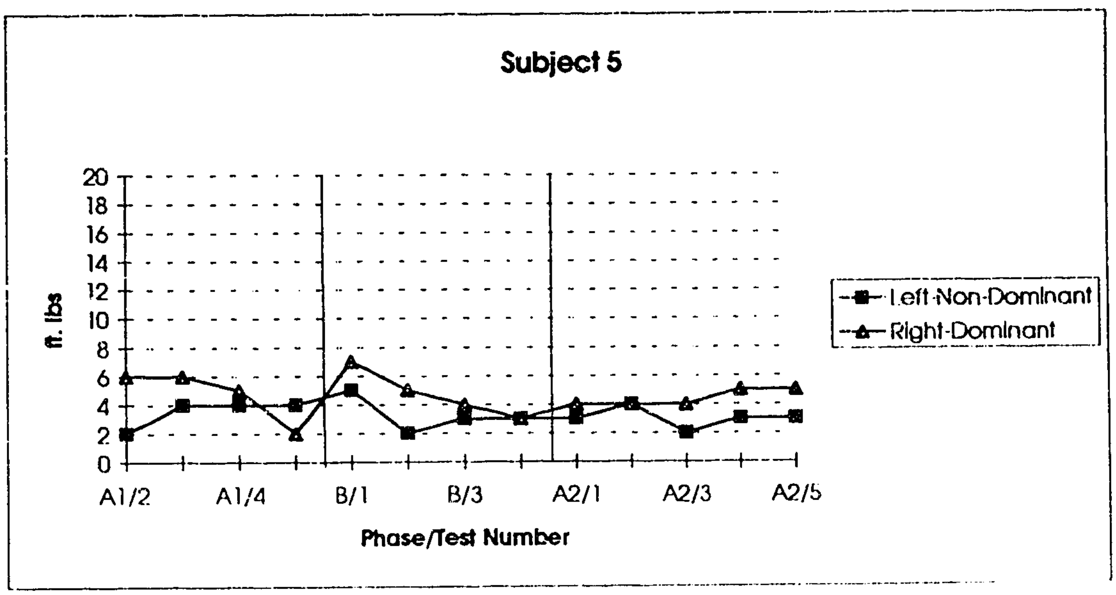




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

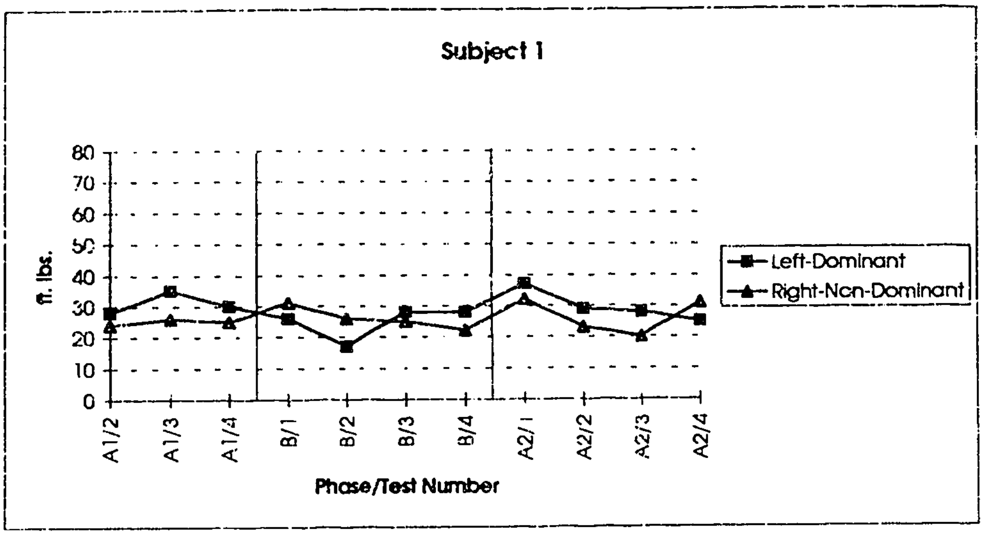
Total Work Flexion 5.24 rad·sec^{-1}

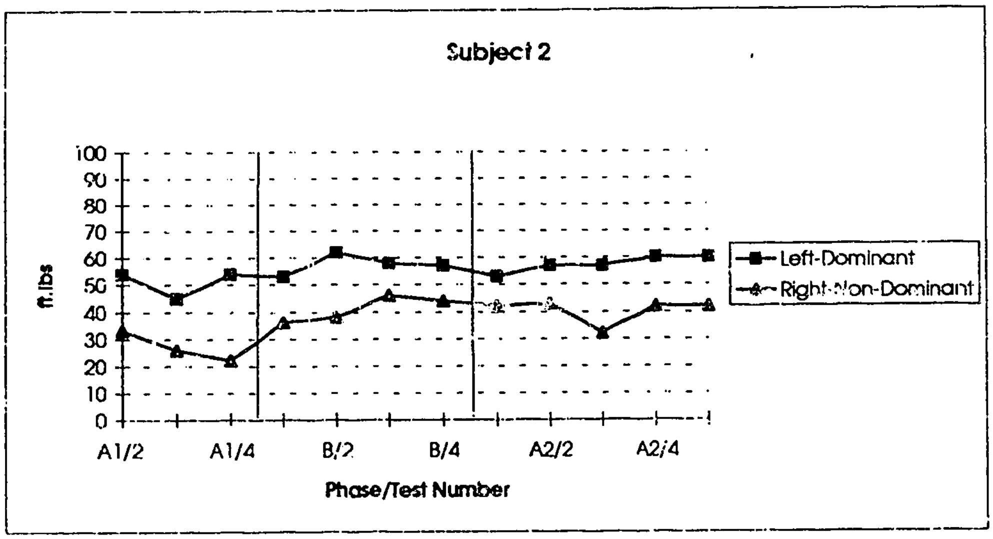


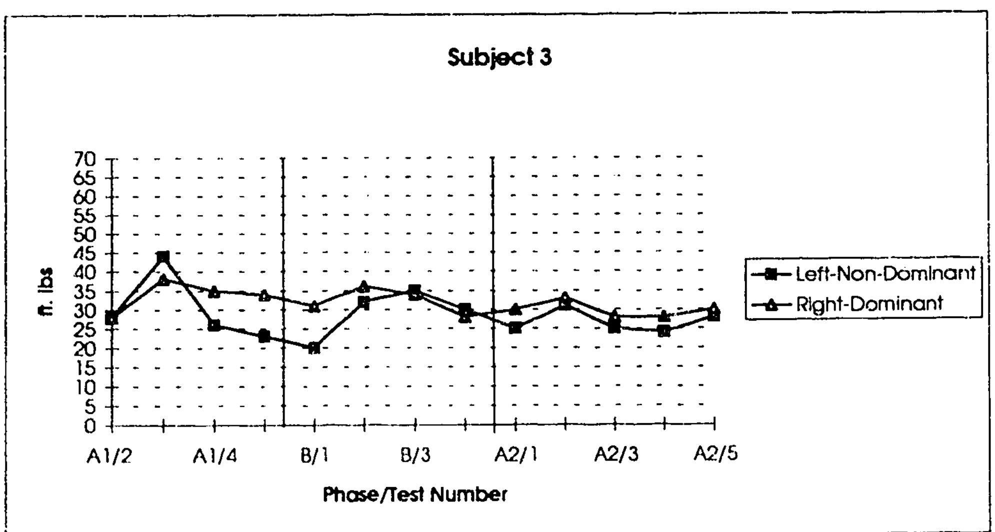


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Total Work Extension 5.24 rad·sec⁻¹

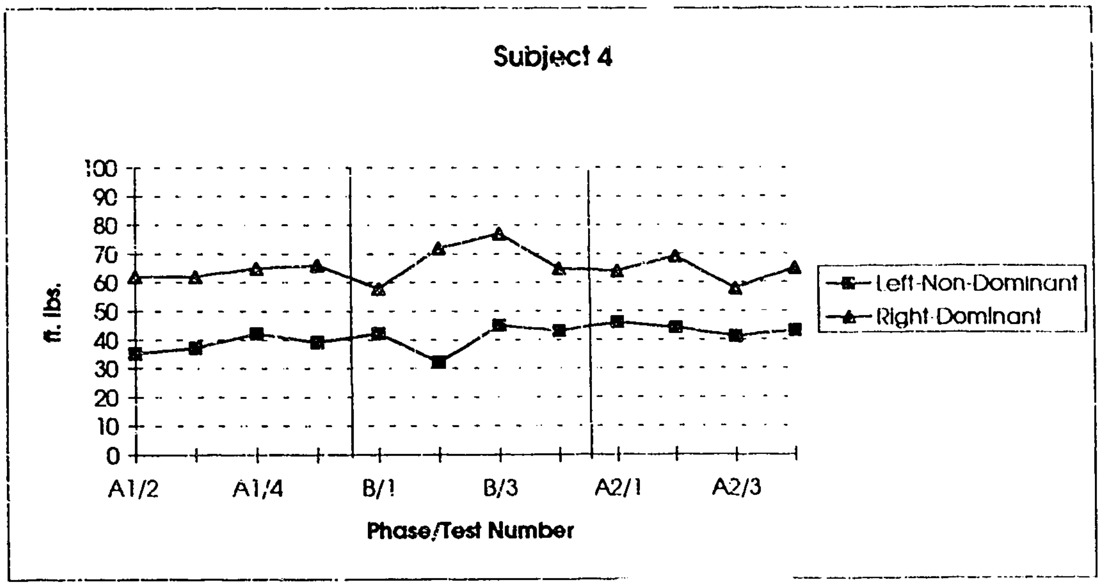


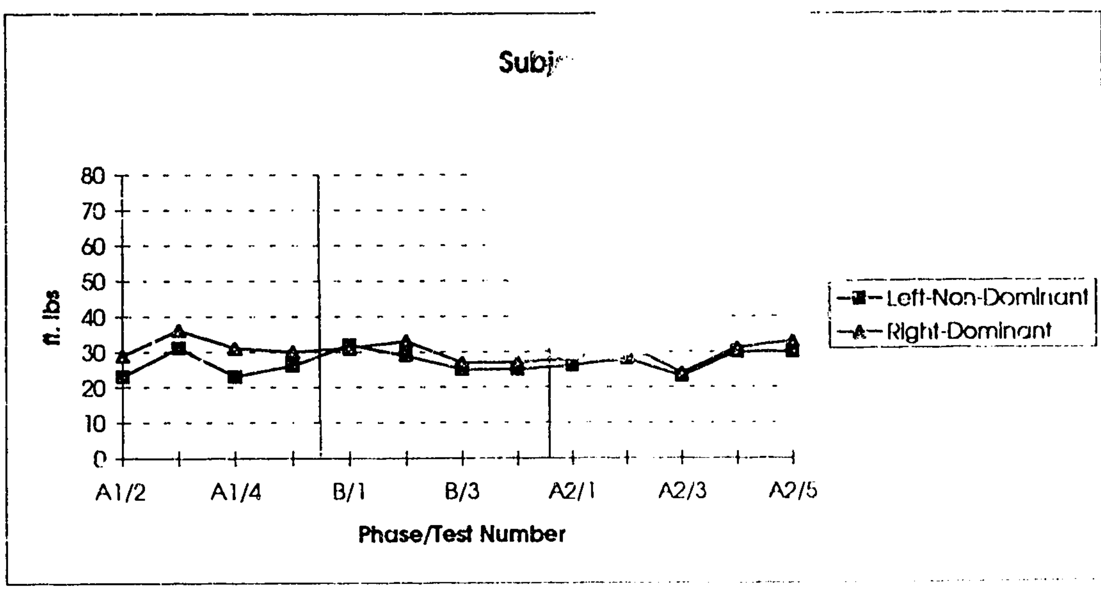




A1 - Baseline Phase   B - Intervention Phase   A2 - Withdrawal Phase

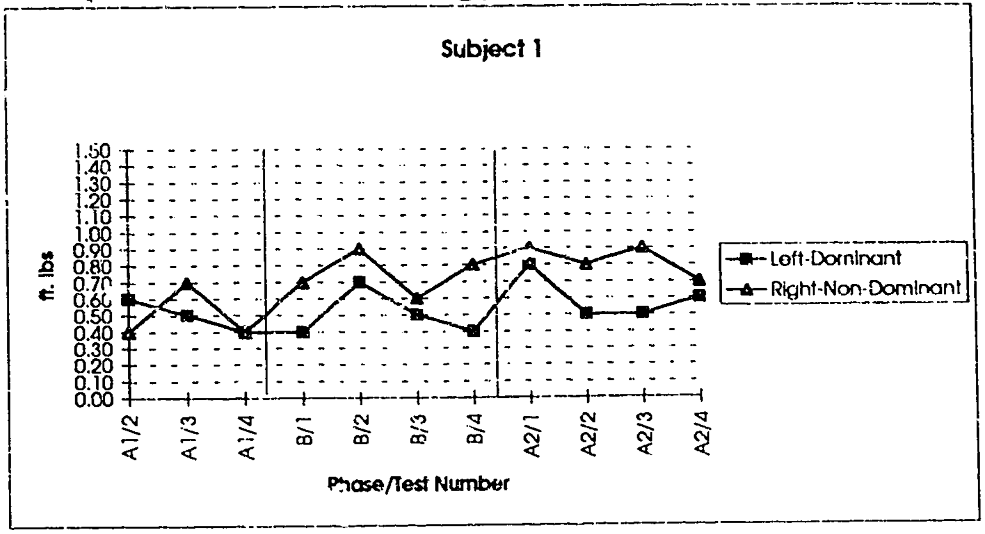
Total Work Extension 5.24 rad·sec⁻¹

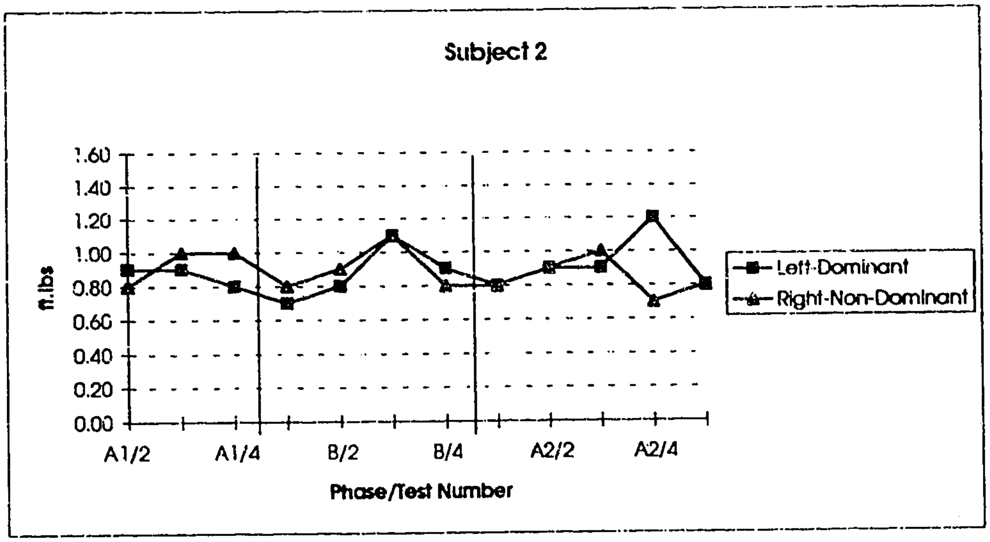


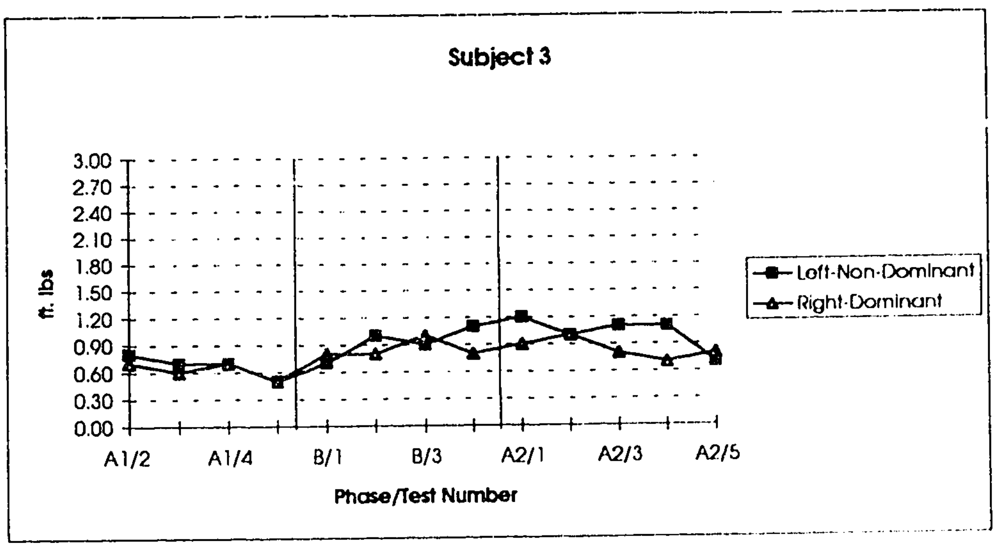


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Torque Acceleration Energy Flexion 0.52 rad·sec⁻¹

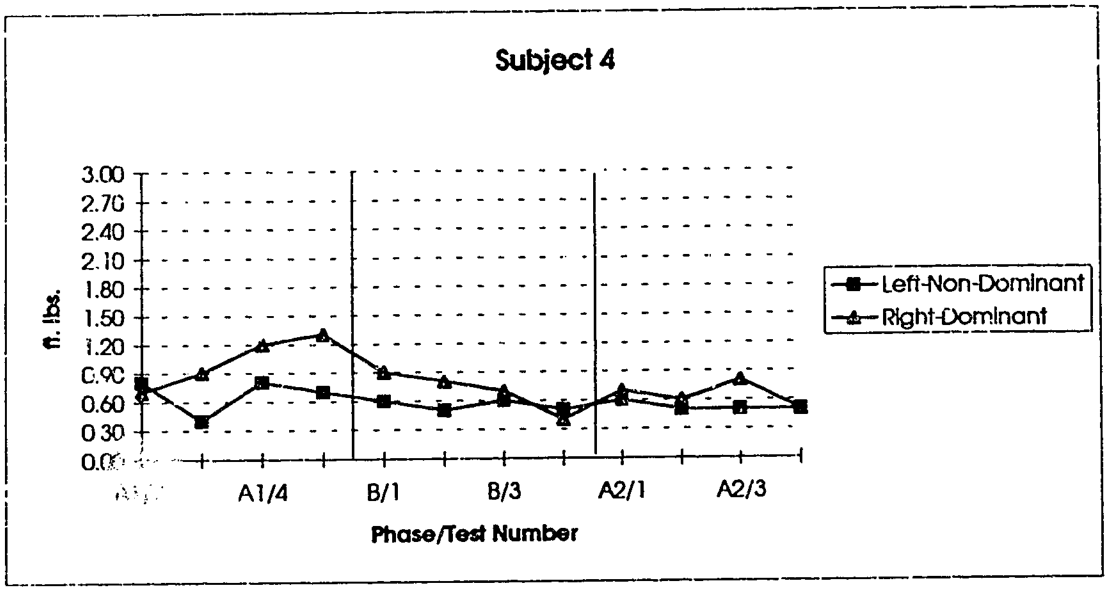


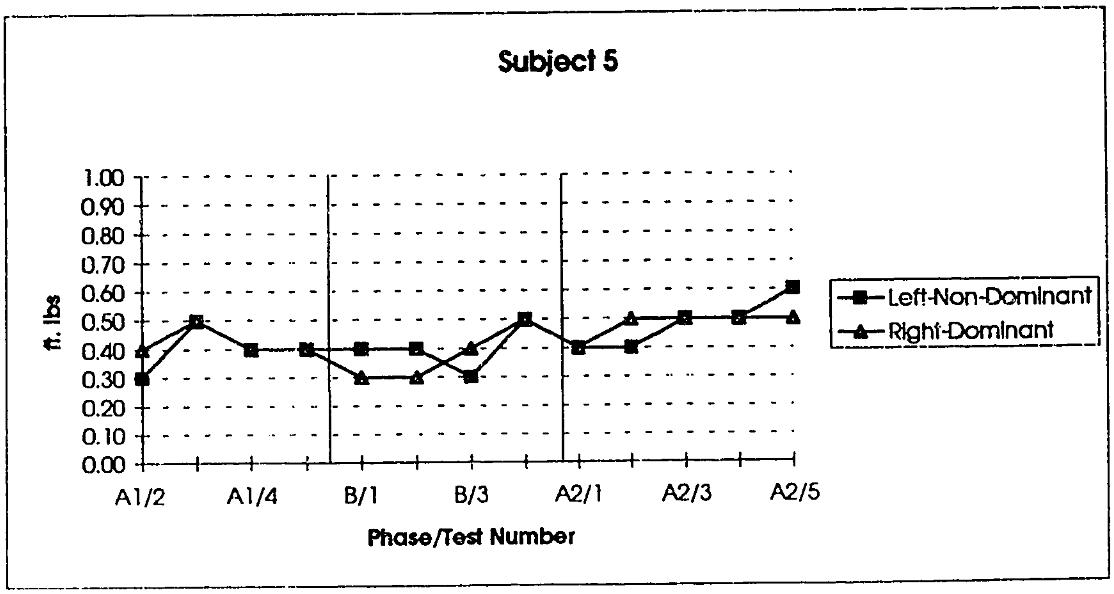




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

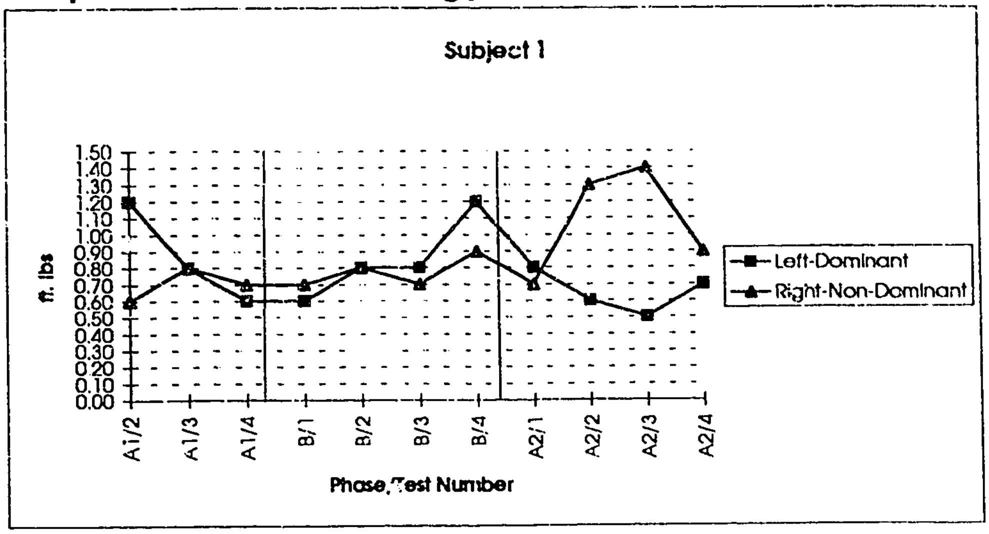
Torque Acceleration Energy Flexion 0.52 rad·sec⁻¹

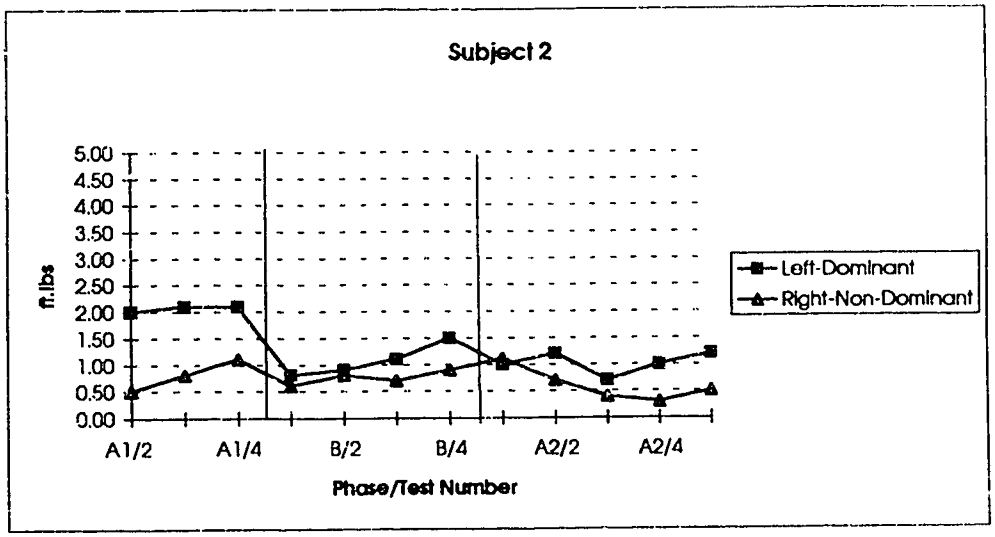


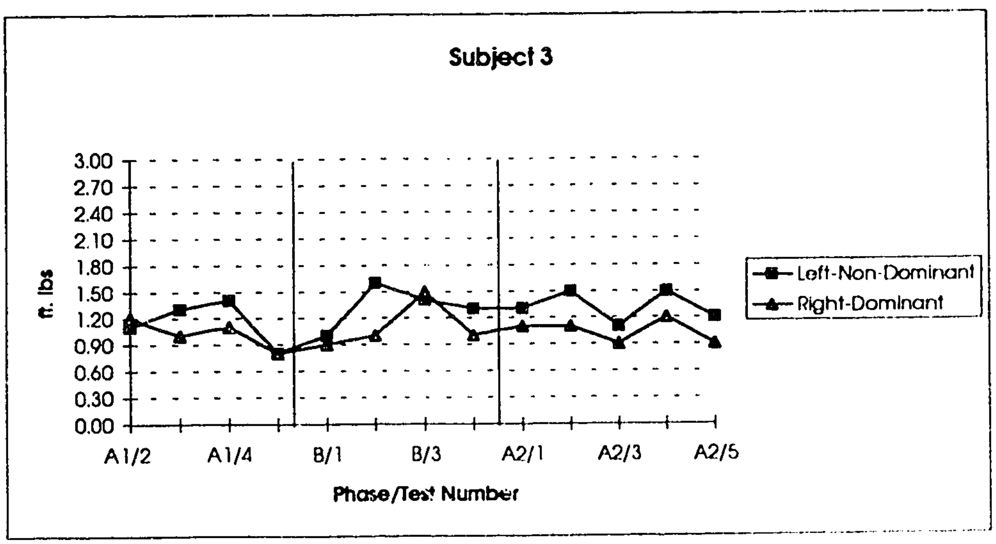


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Torque Acceleration Energy Extension 0.52 rad·sec⁻¹

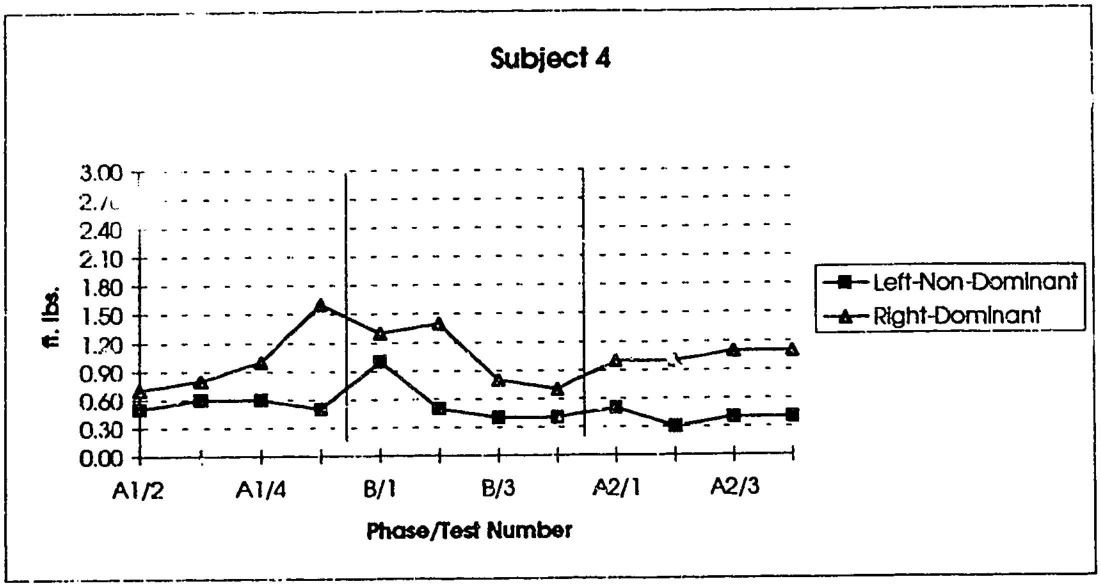


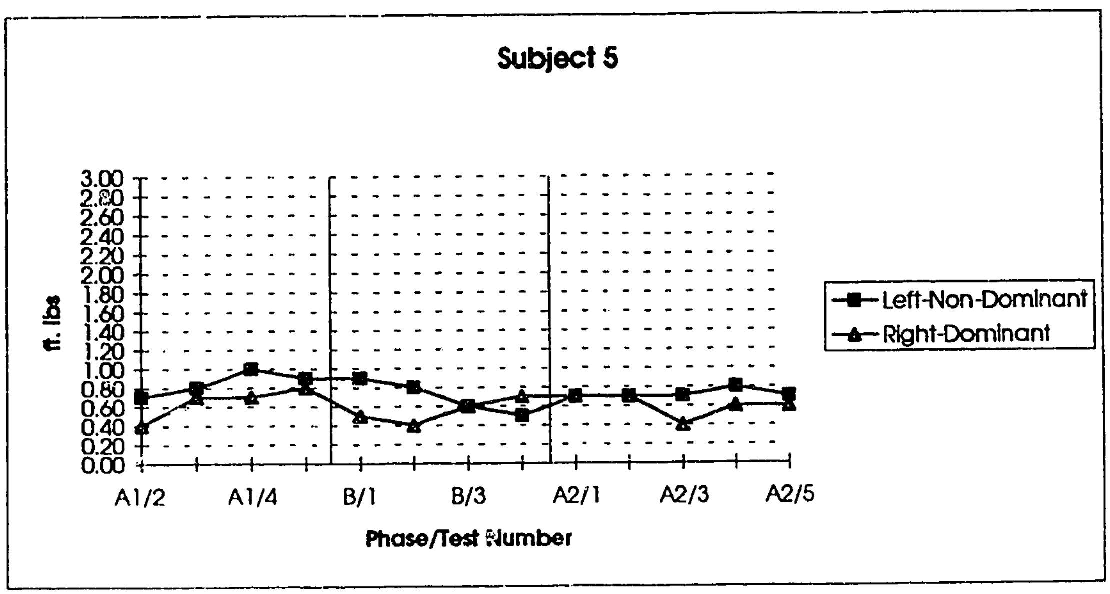




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

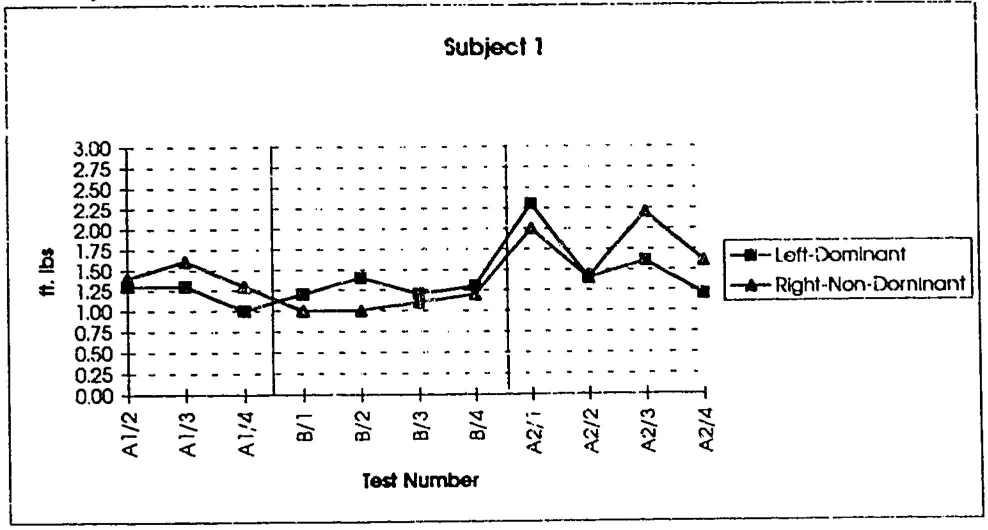
Torque Acceleration Energy Extension 0.52 rad·sec^{-1}

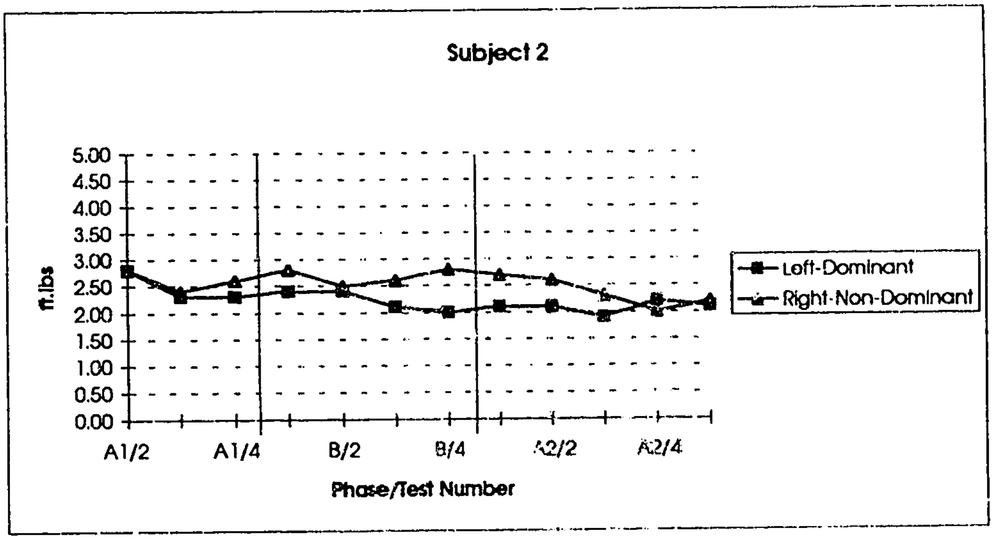


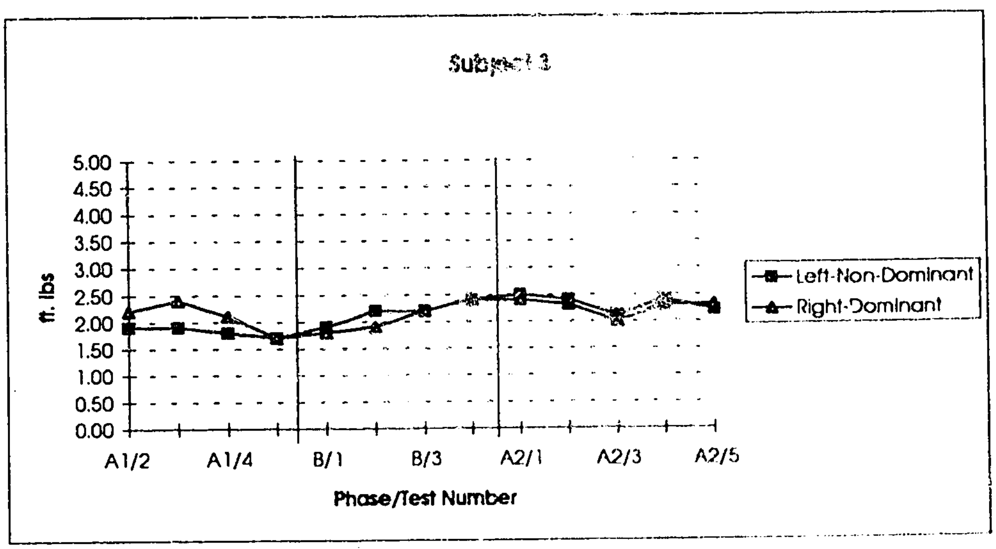


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Torque Acceleration Energy Flexion 1.05 rad·sec⁻¹

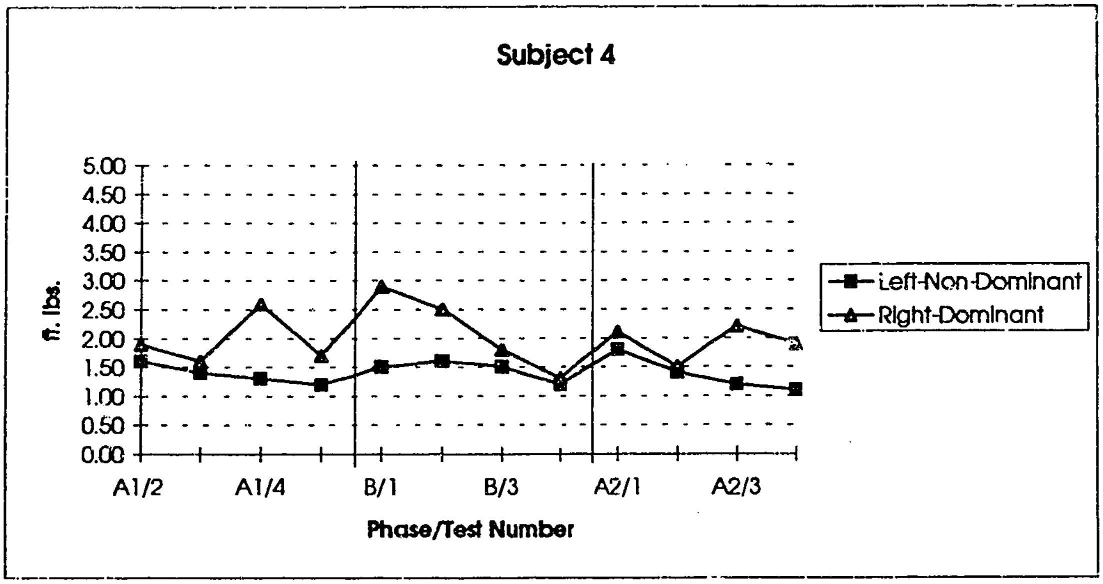


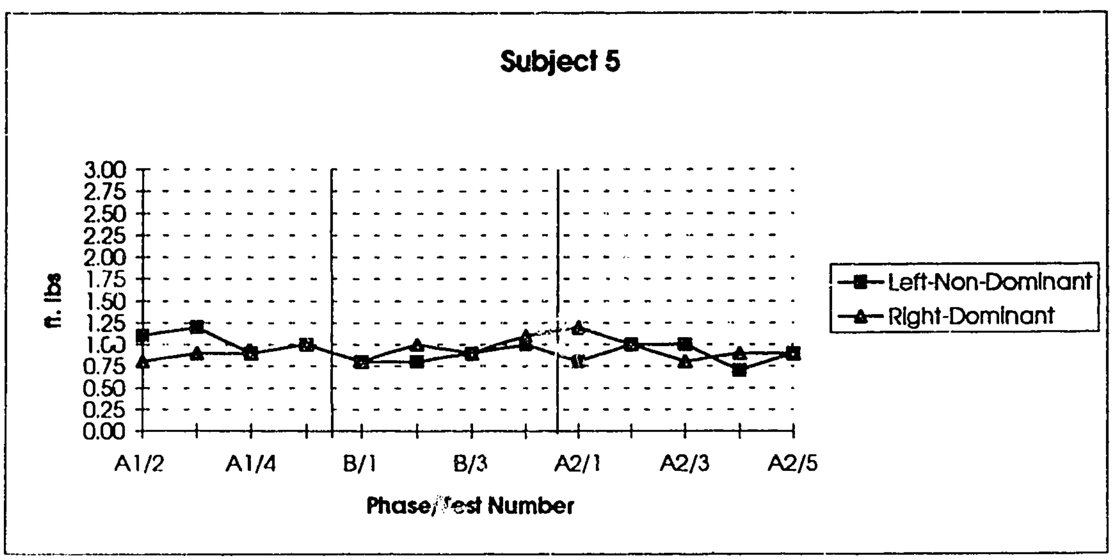




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

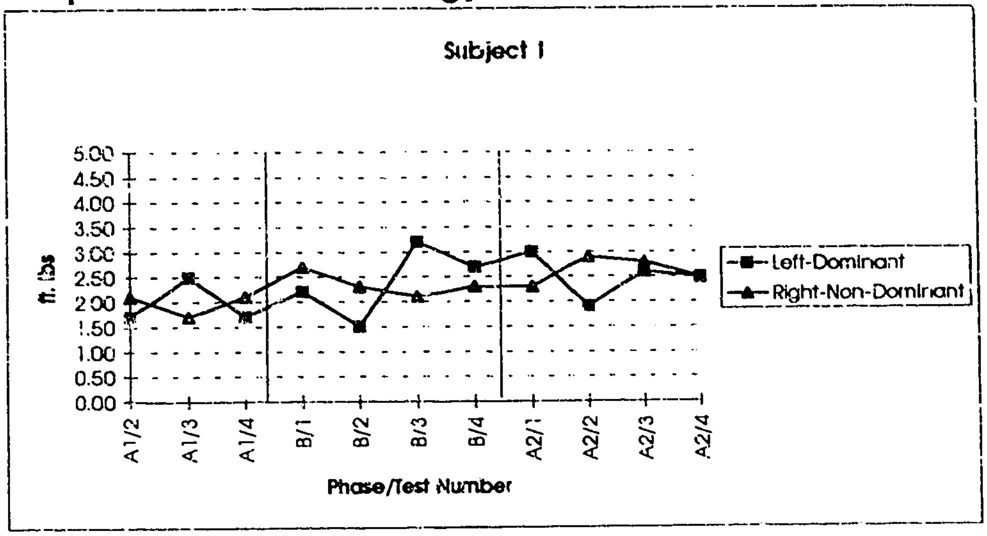
Torque Acceleration Energy Flexion 1.05 rad·sec^{-1}

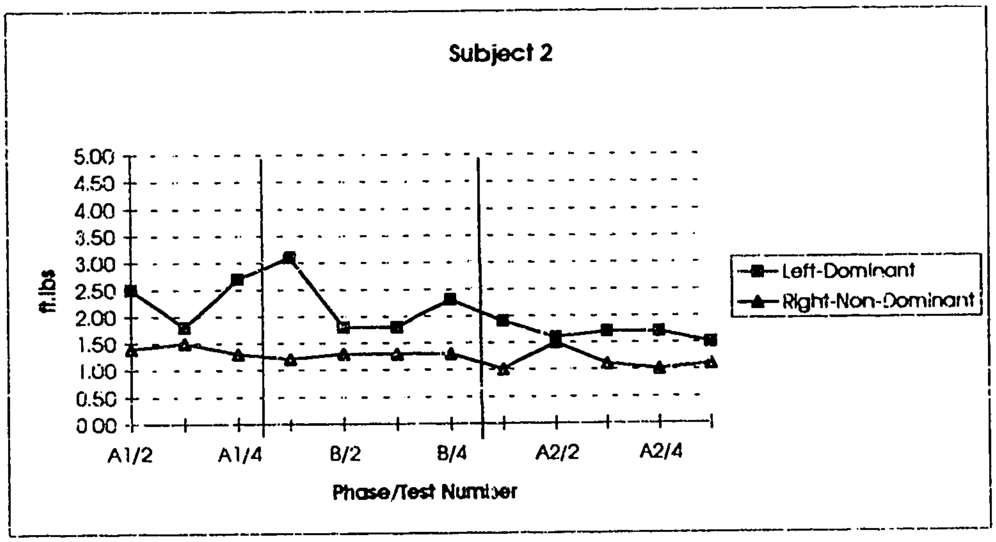


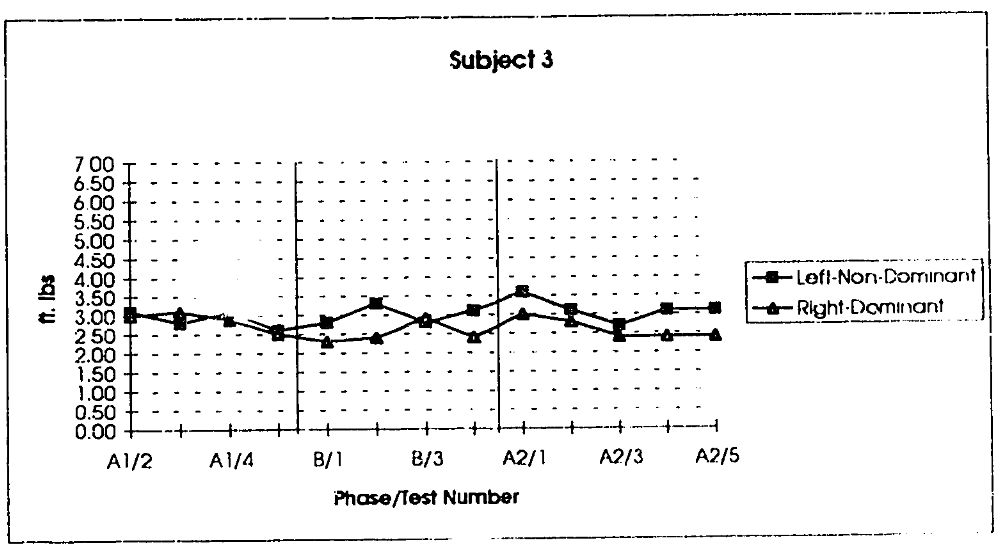


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Torque Acceleration Energy Extension 1.05 rad·sec⁻¹

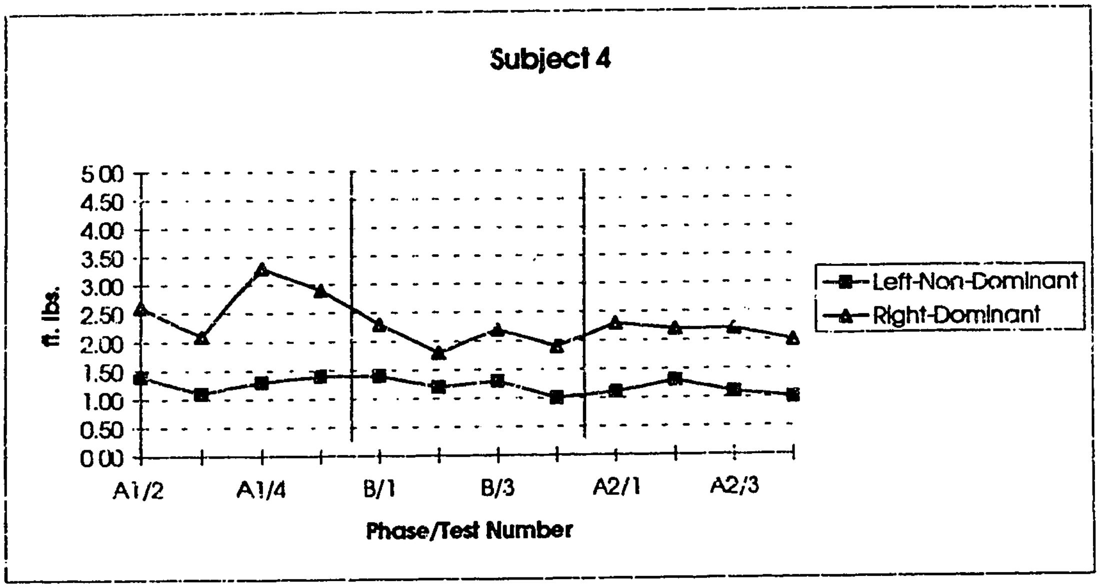


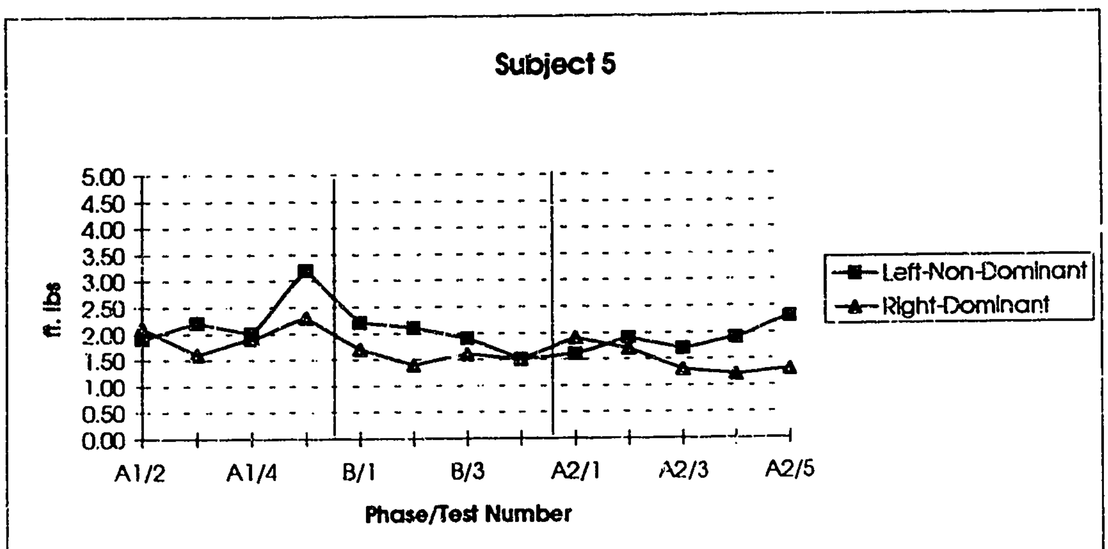




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

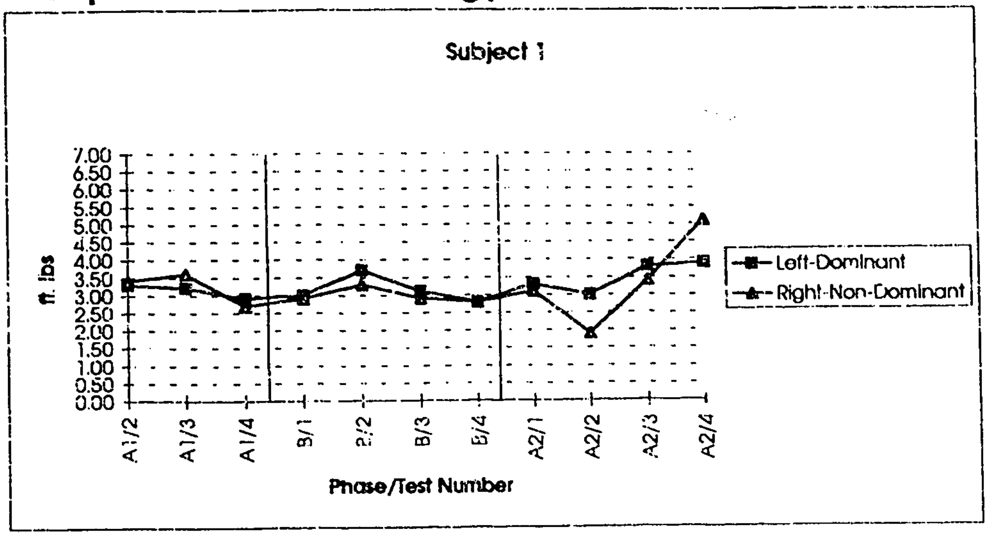
Torque Acceleration Energy Extension 1.05 rad·sec⁻¹

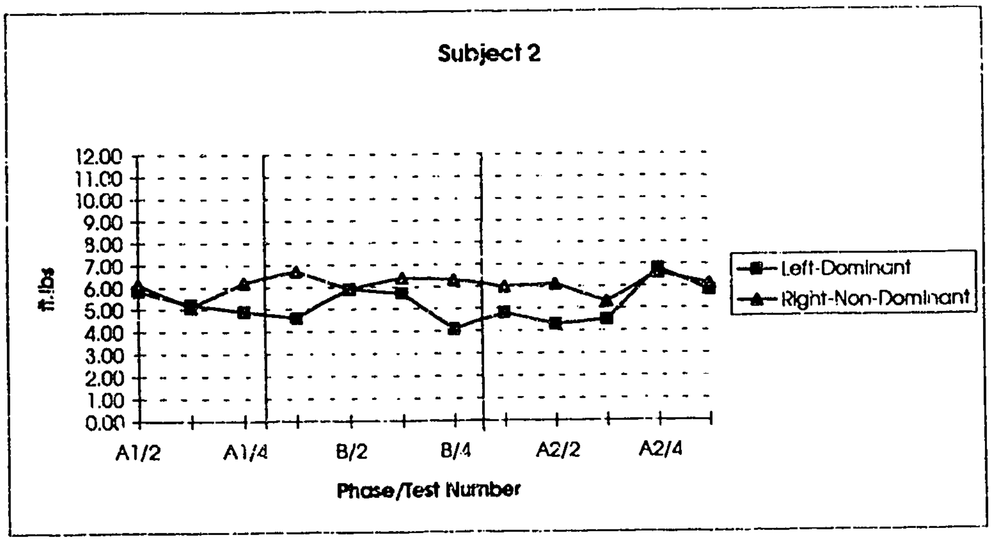


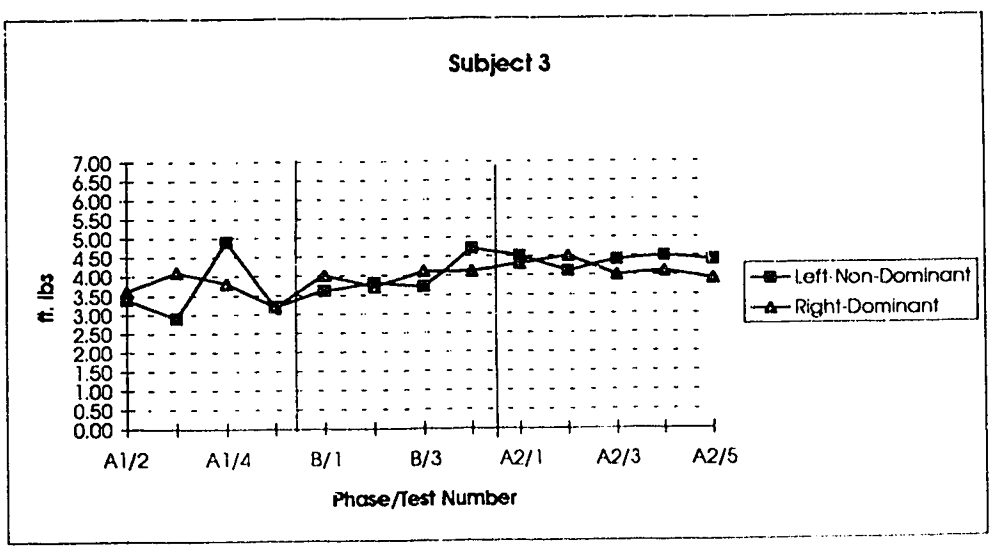


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Torque Acceleration Energy Flexion 2.09 $rad \cdot sec^{-1}$

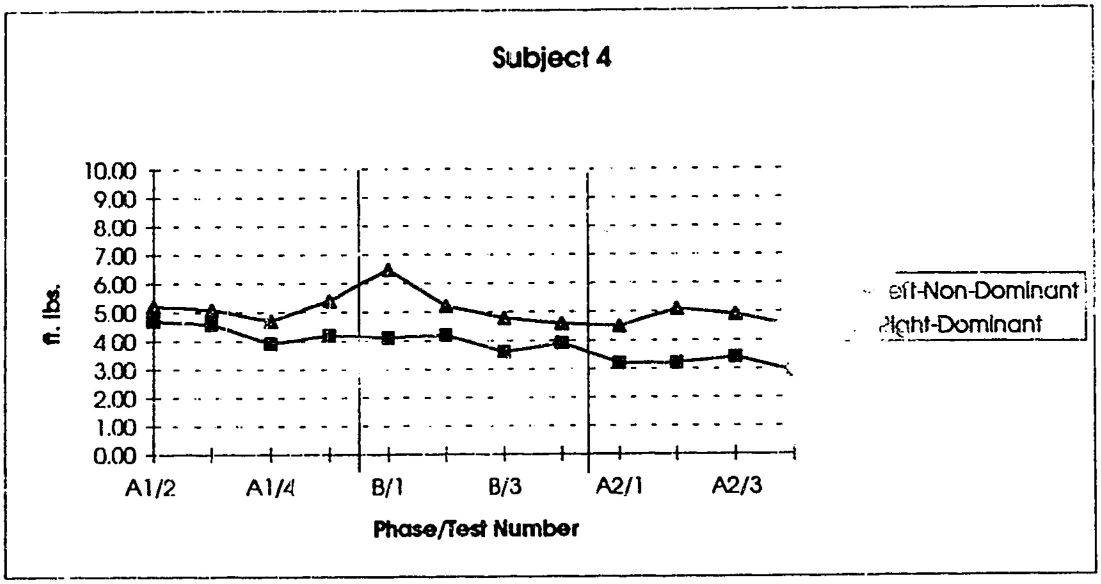


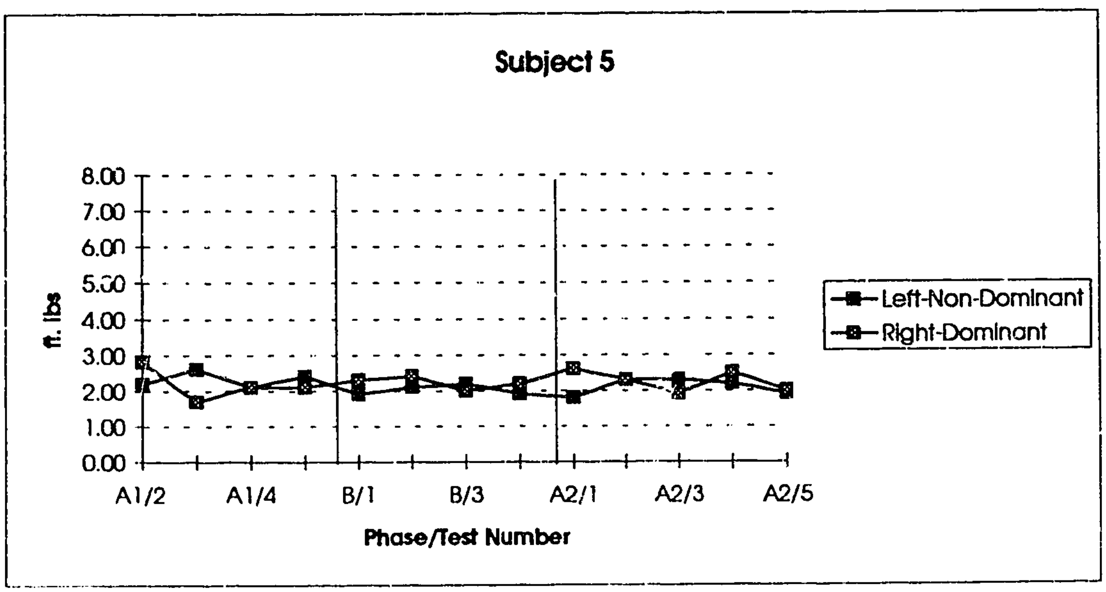




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

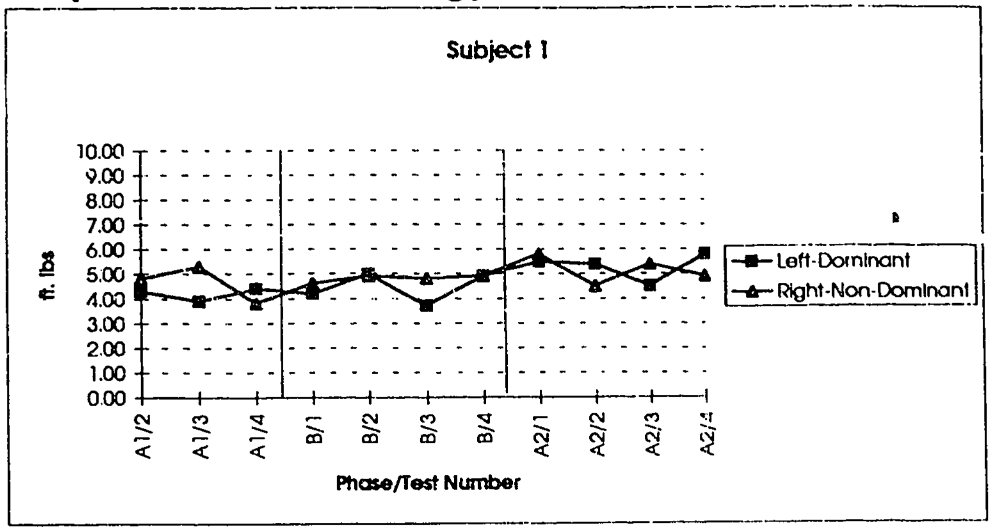
Torque Acceleration Energy Flexion 2.09 rad·sec^{-1}

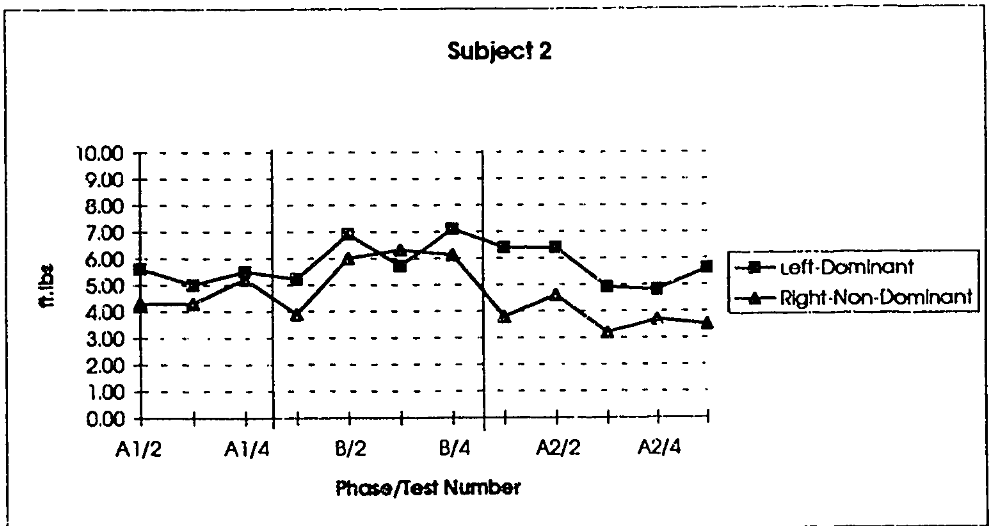


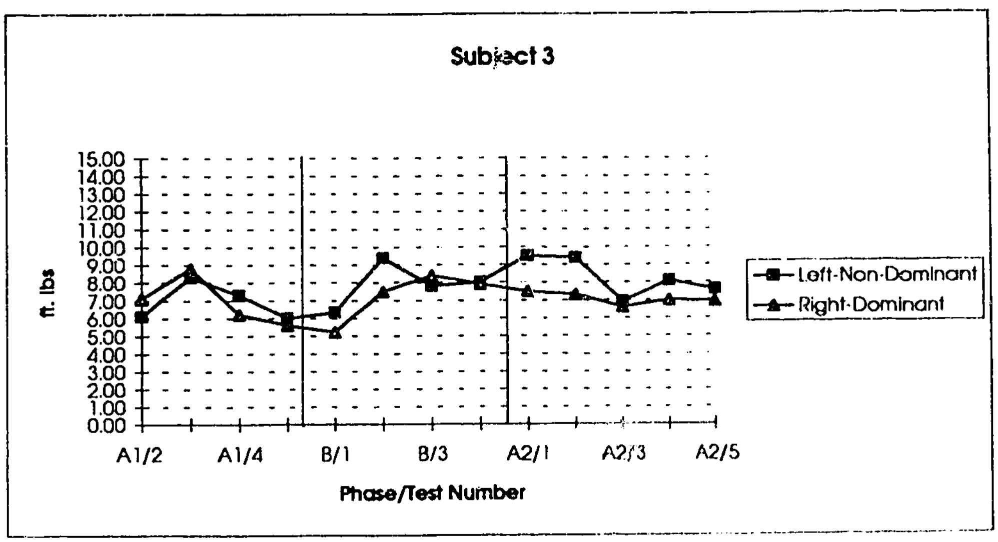


A1 - Baseline Phase   B - Intervention Phase   A2 - Withdrawal Phase

Torque Acceleration Energy Extension 2.09 rad·sec⁻¹

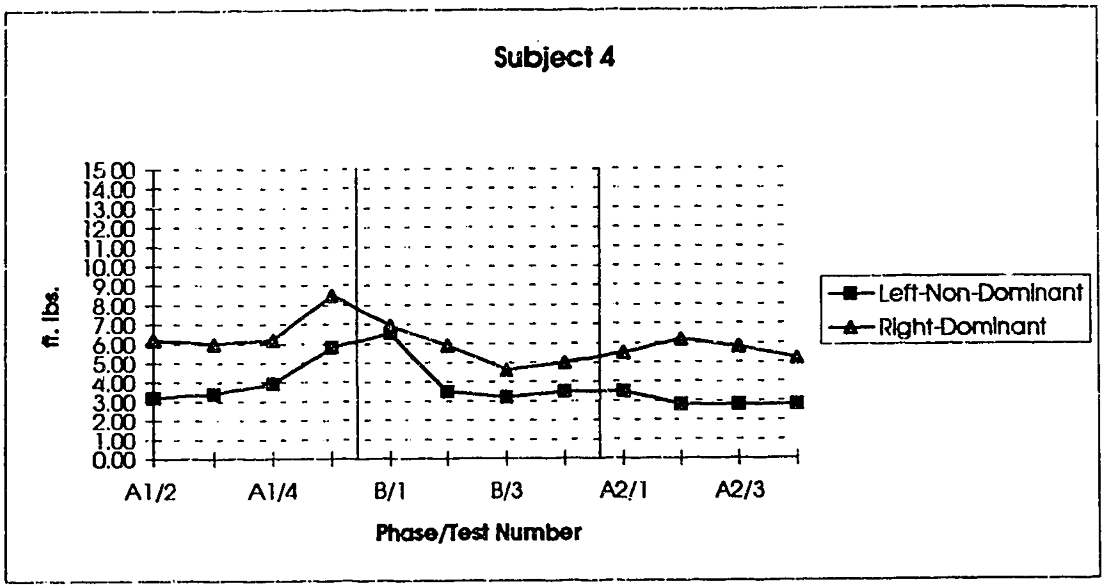


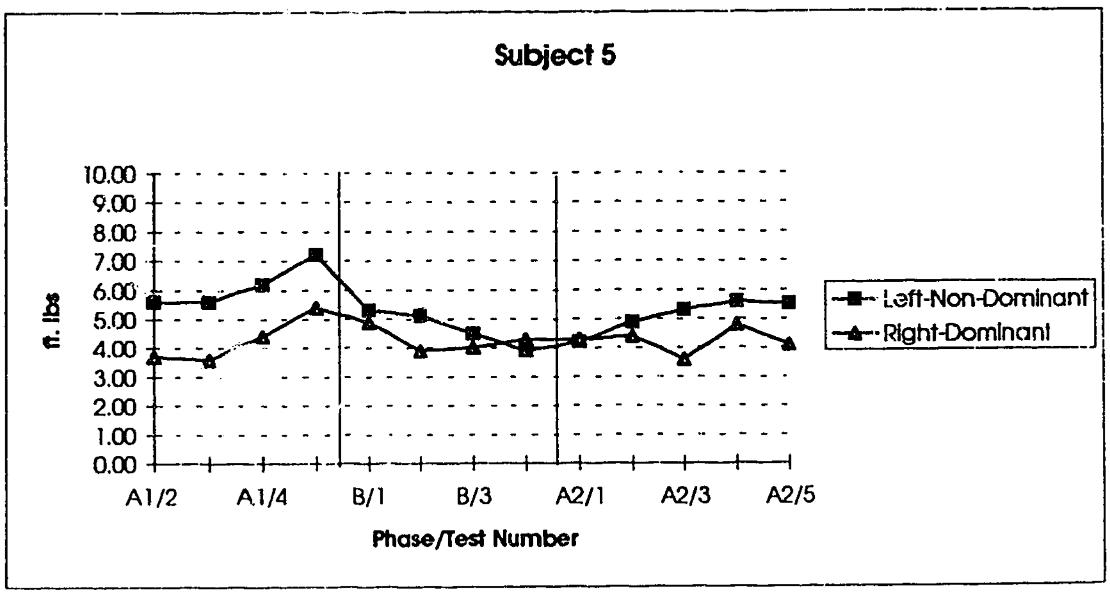




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

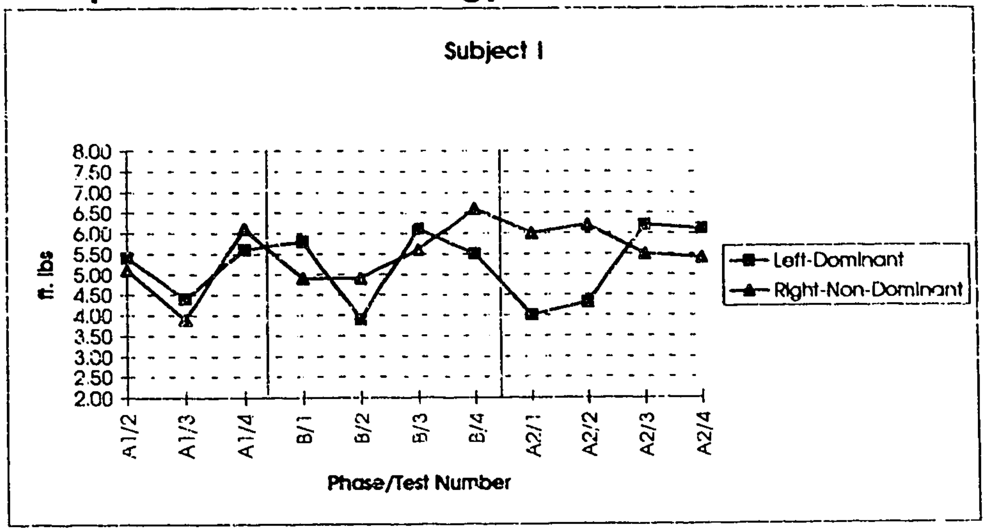
Torque Acceleration Energy Extension 2.09 rad·sec⁻¹

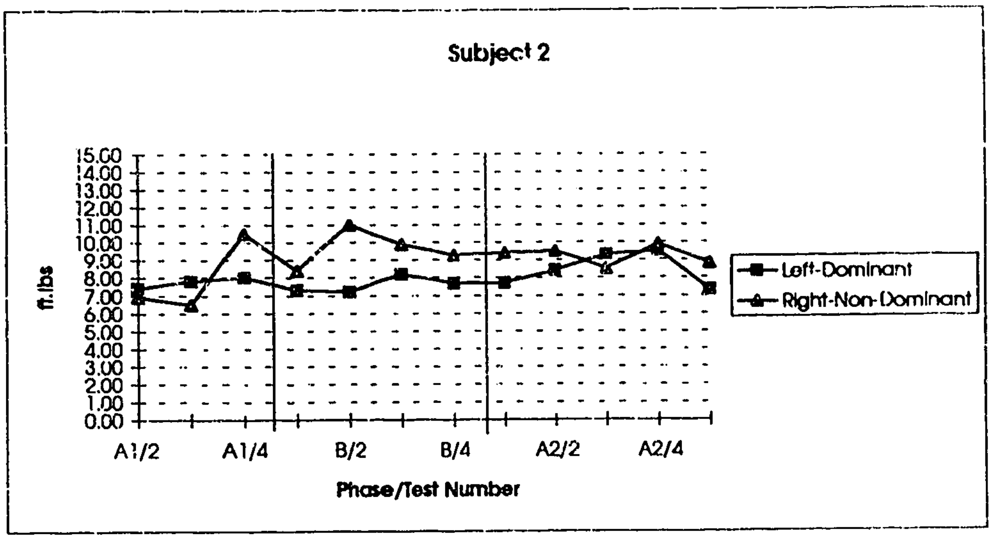


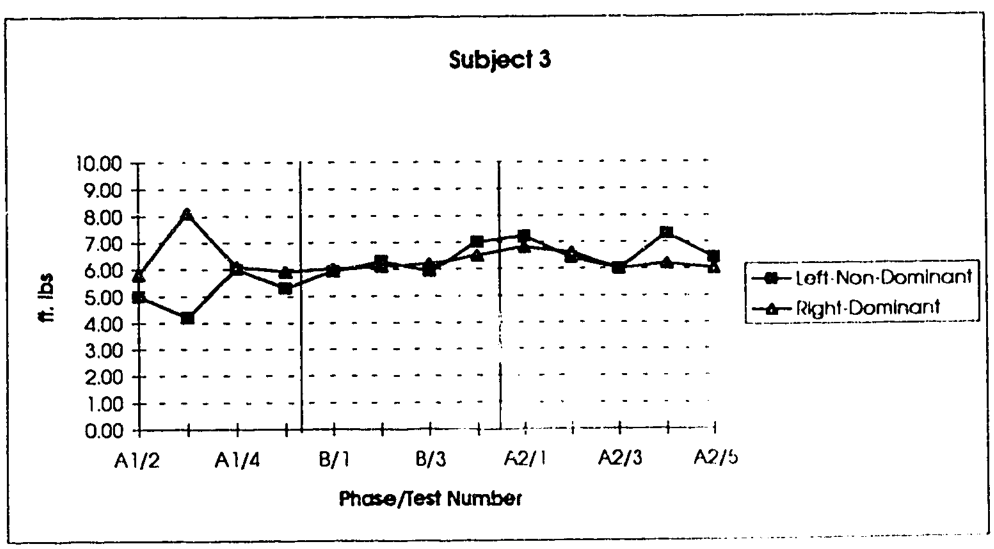


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Torque Acceleration Energy Flexion 3.14 rad·sec⁻¹

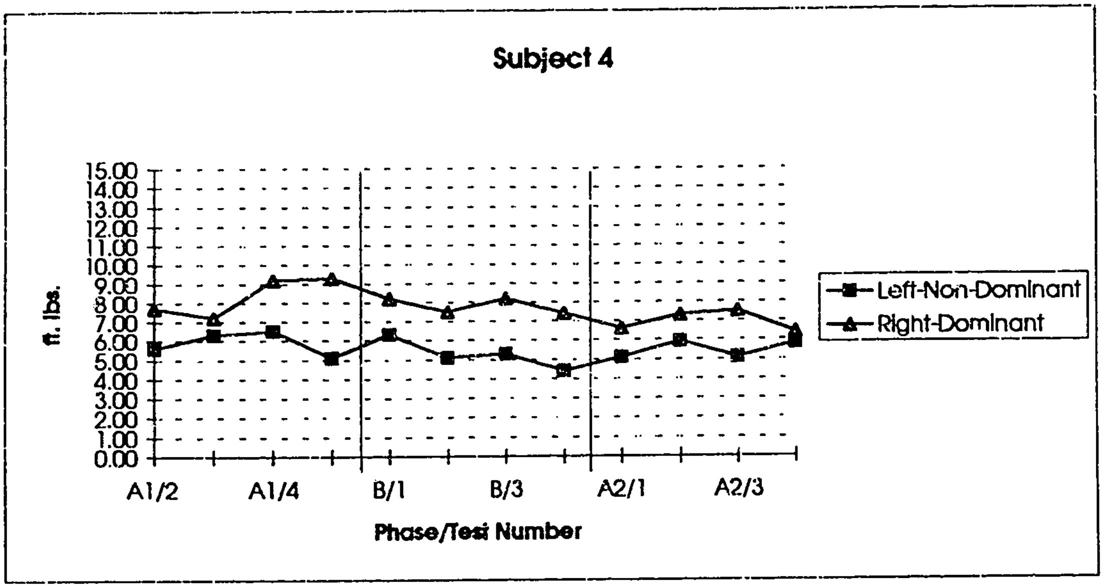


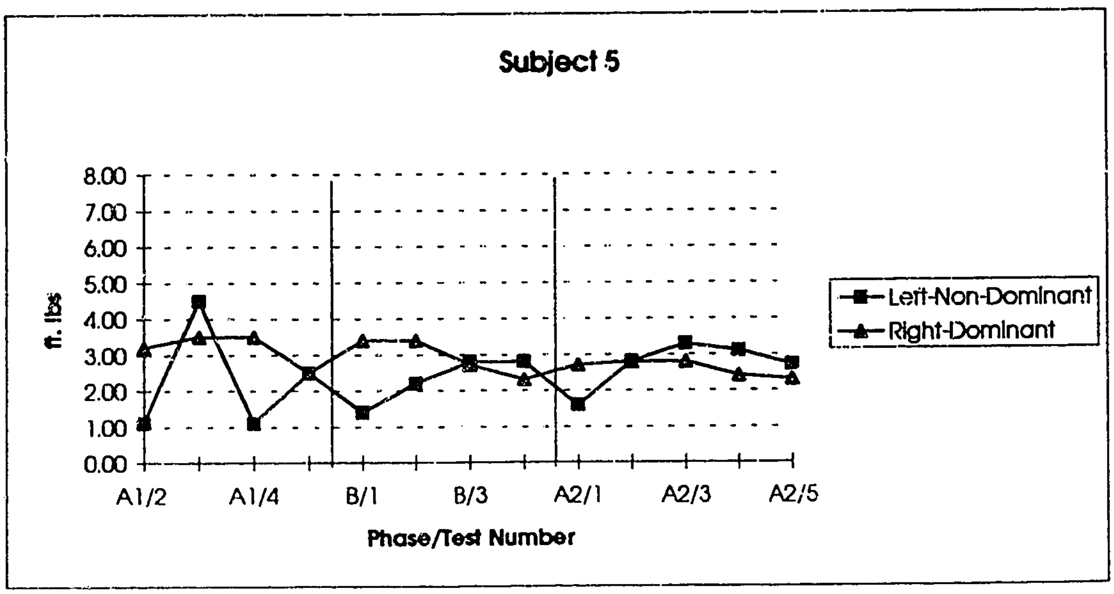




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

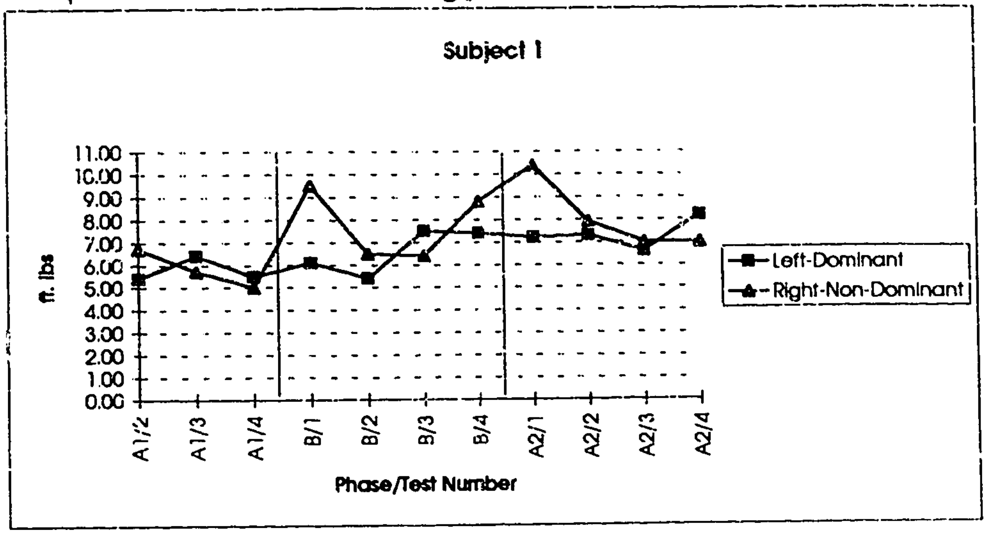
Torque Acceleration Energy Flexion 3.14 rad·sec⁻¹

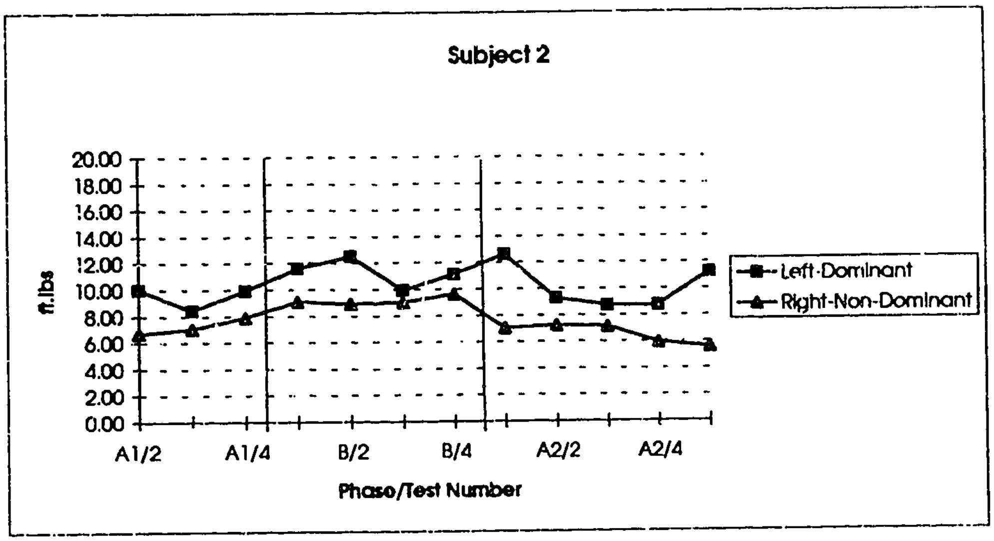


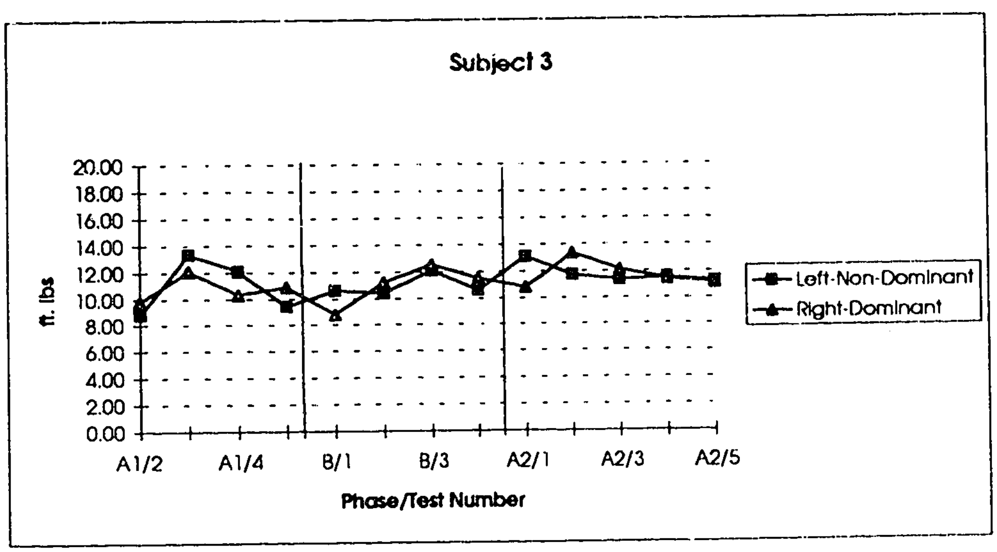


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Torque Acceleration Energy Extension 3.14 rad·sec⁻¹

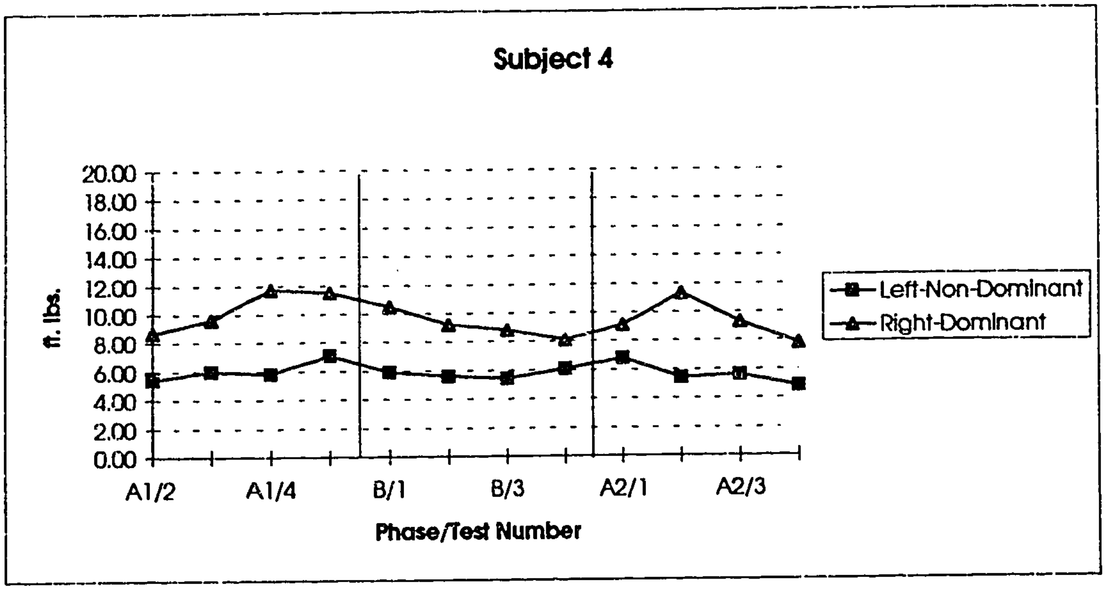


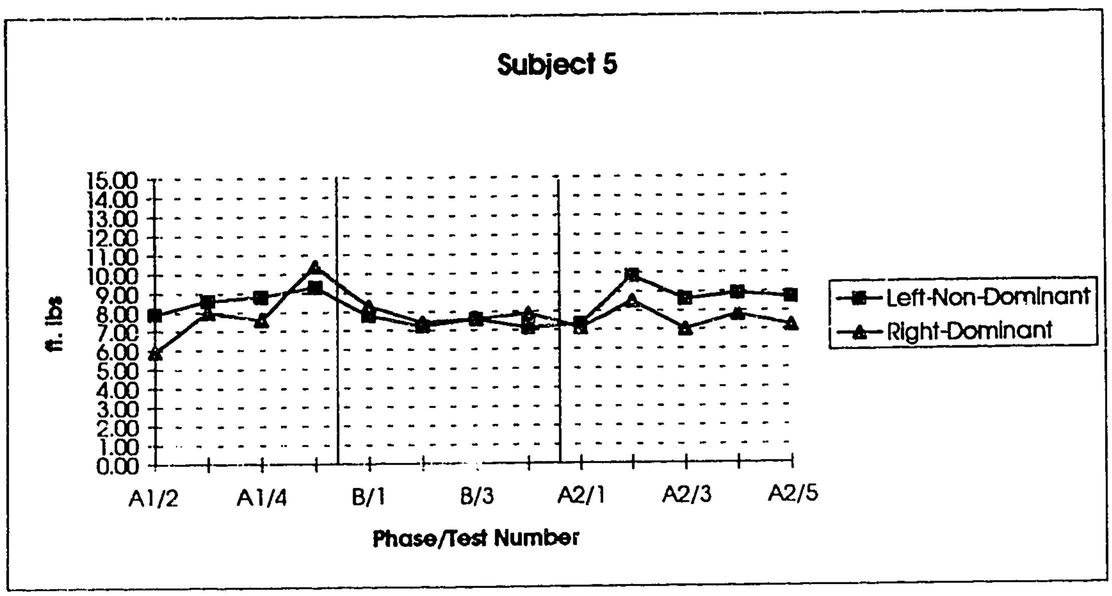




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

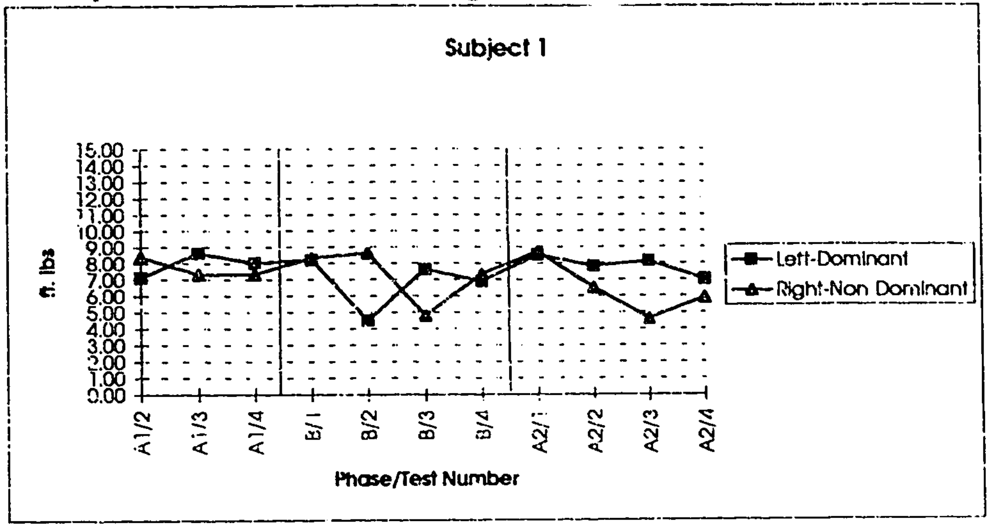
Torque Acceleration Energy Extension 3.14 rad·sec[-1]

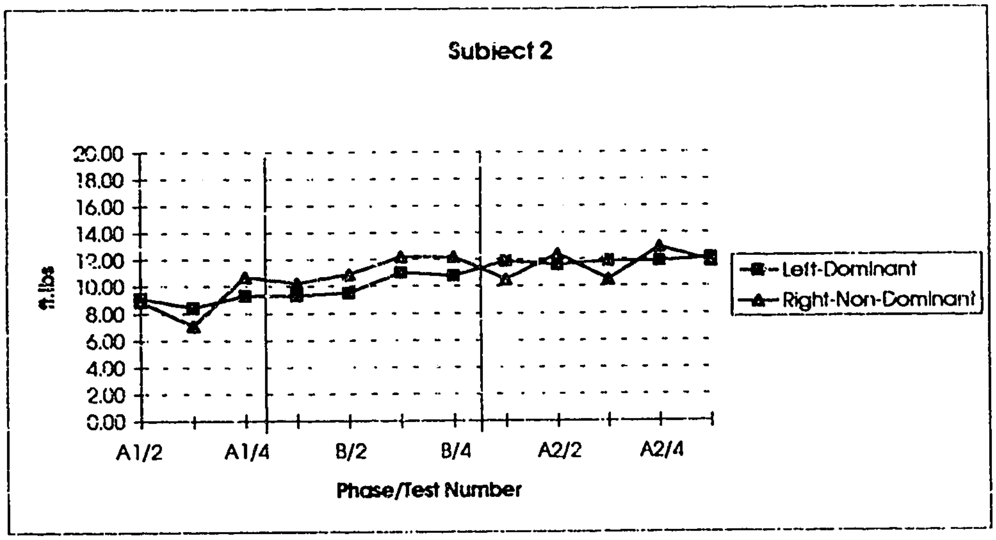


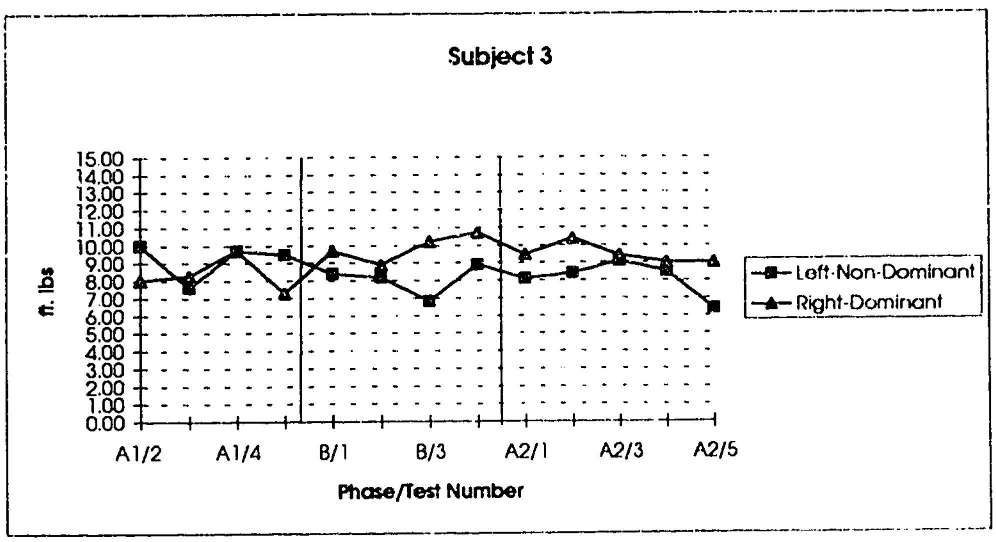


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Torque Acceleration Energy Flexion 4.19 rad·sec⁻¹

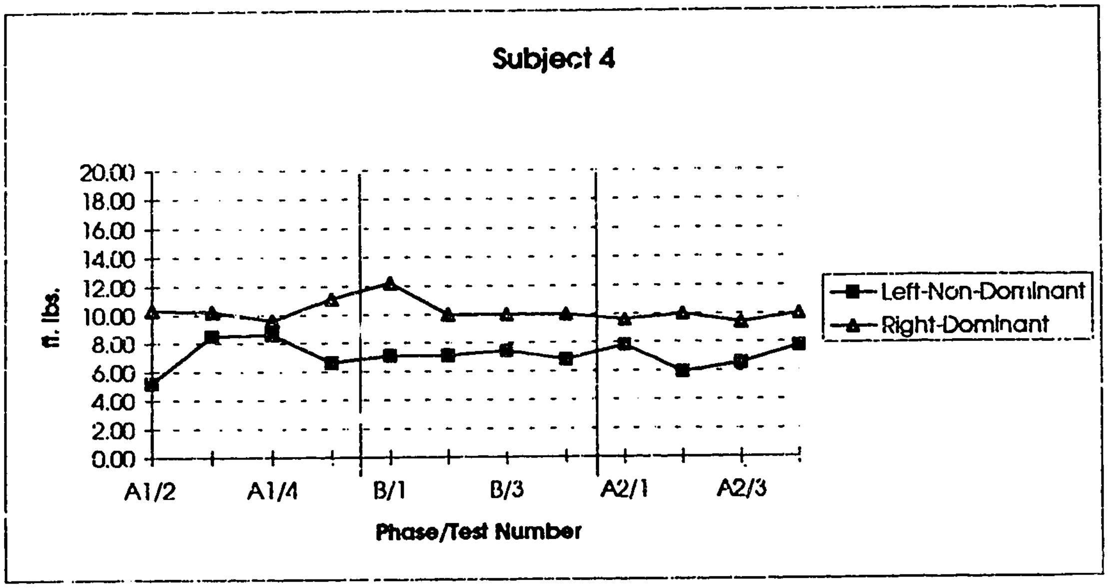


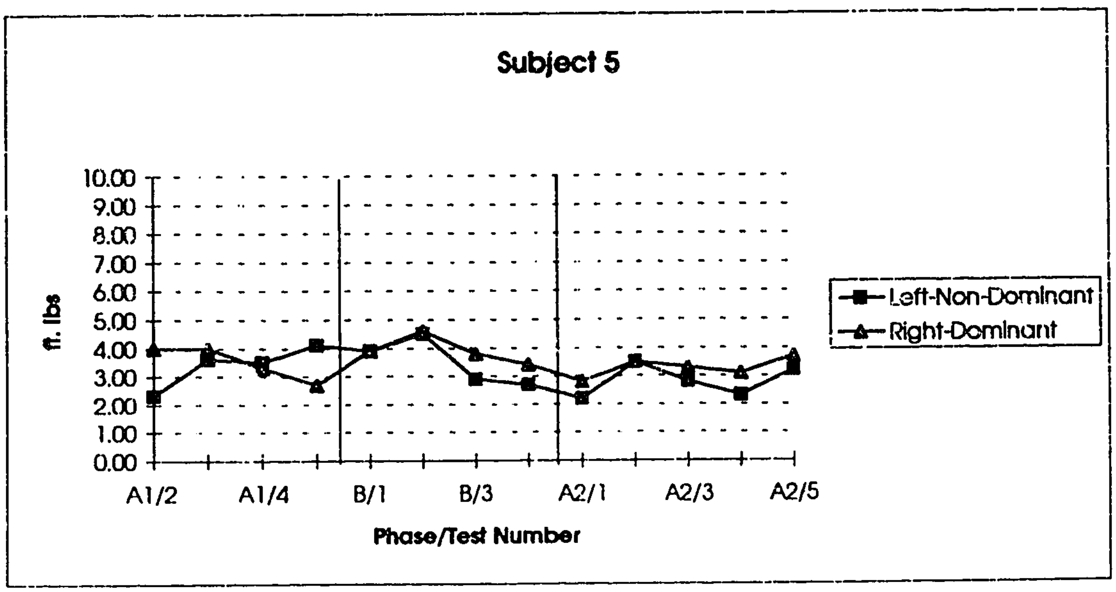




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

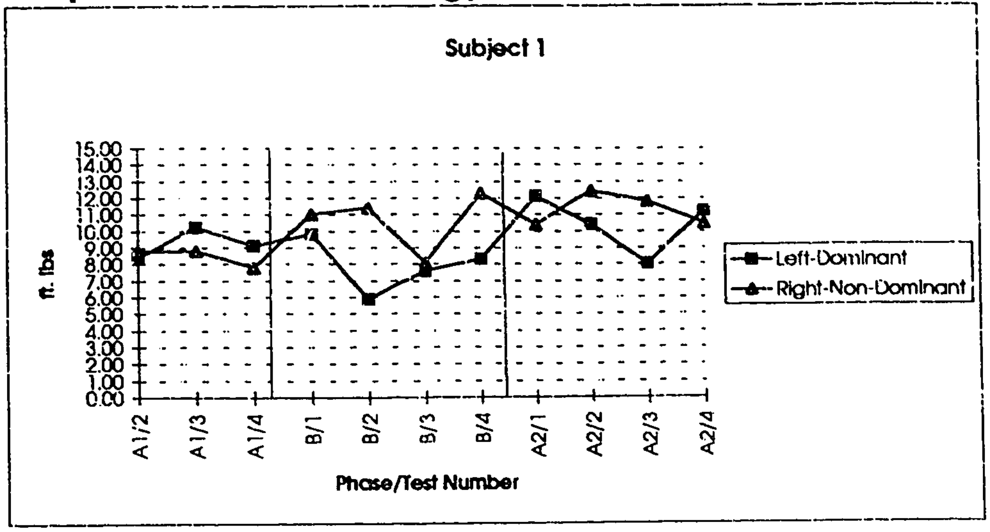
Torque Acceleration Energy Flexion 4.19 rad·sec⁻¹

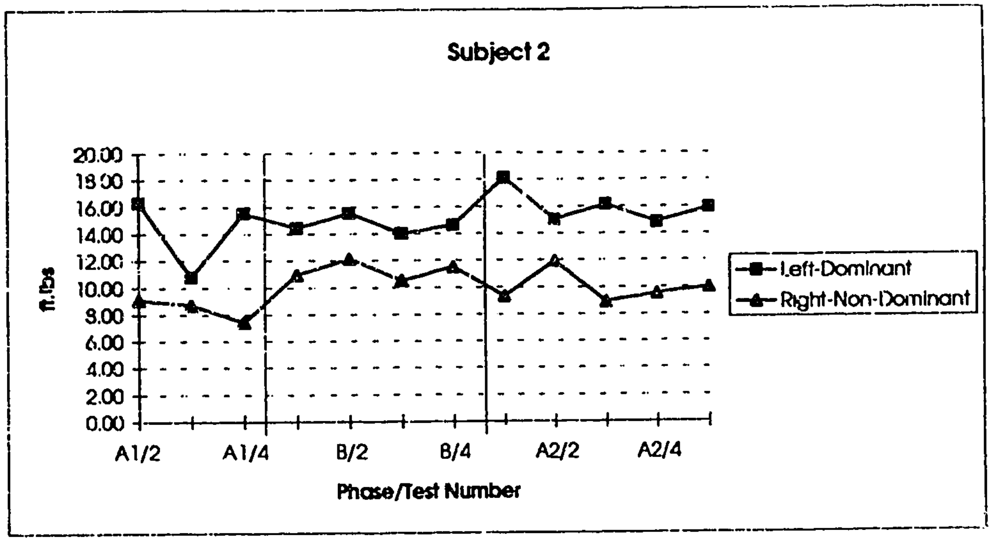


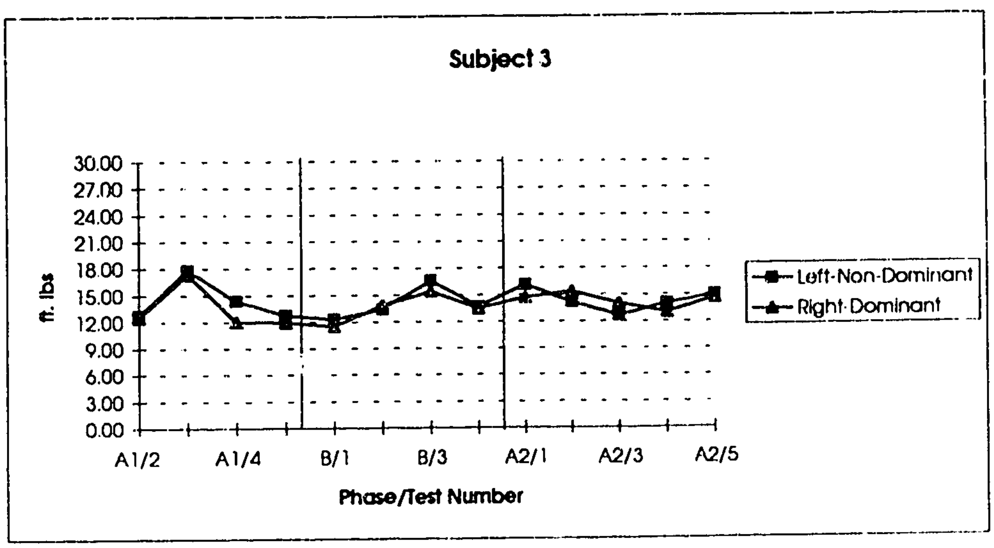


A1 - Baseline Phase   B - Intervention Phase   A2 - Withdrawal Phase

Torque Acceleration Energy Extension 4.19 rad·sec⁻¹

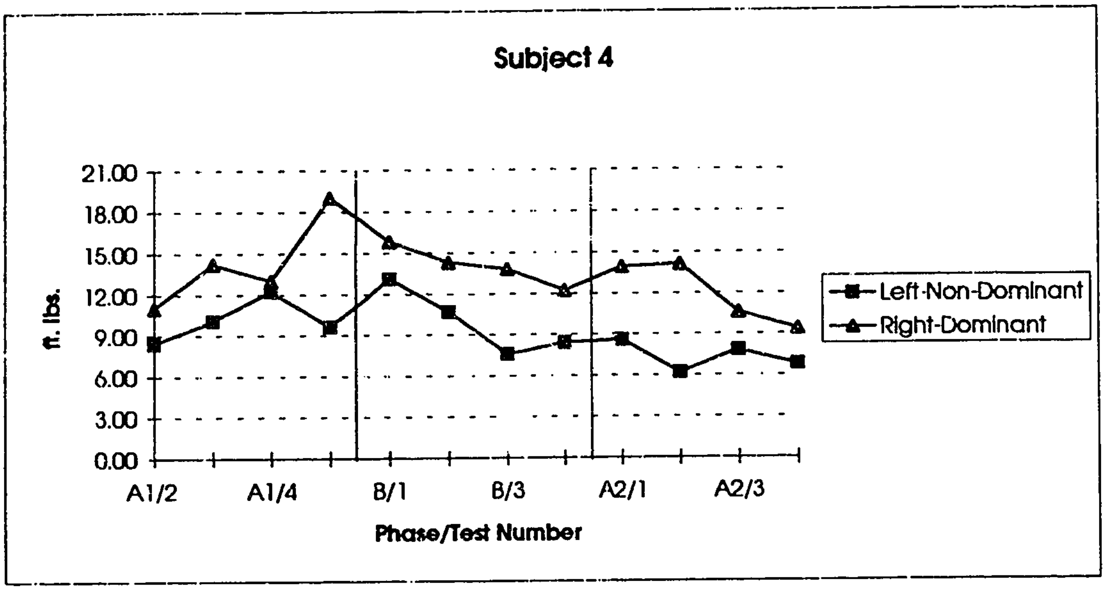


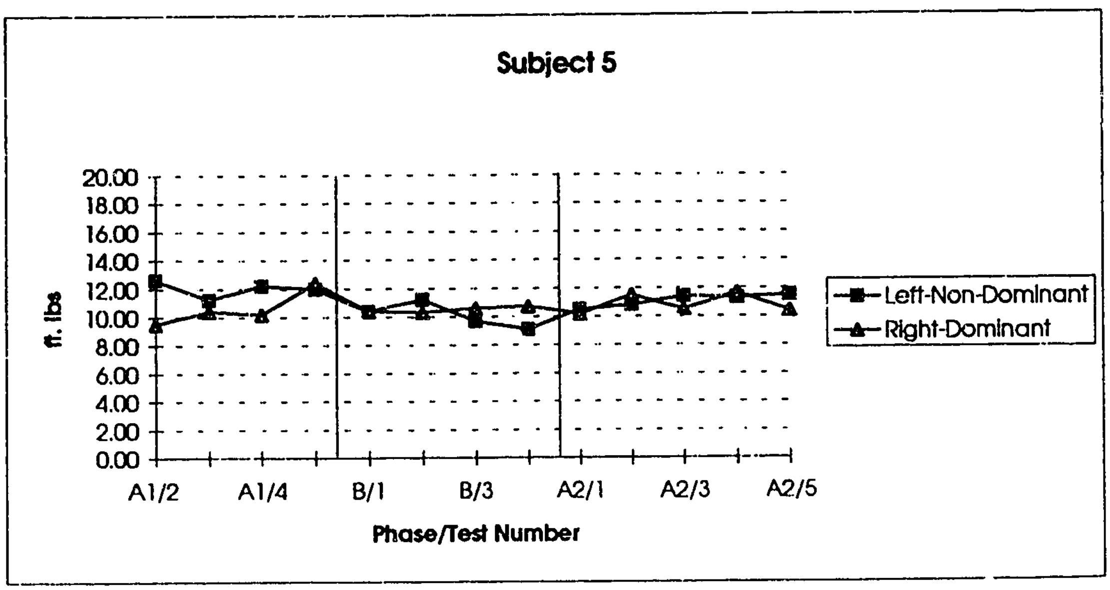




A1 - Baseline Phase   B - Intervention Phase   A2 - Withdrawal Phase

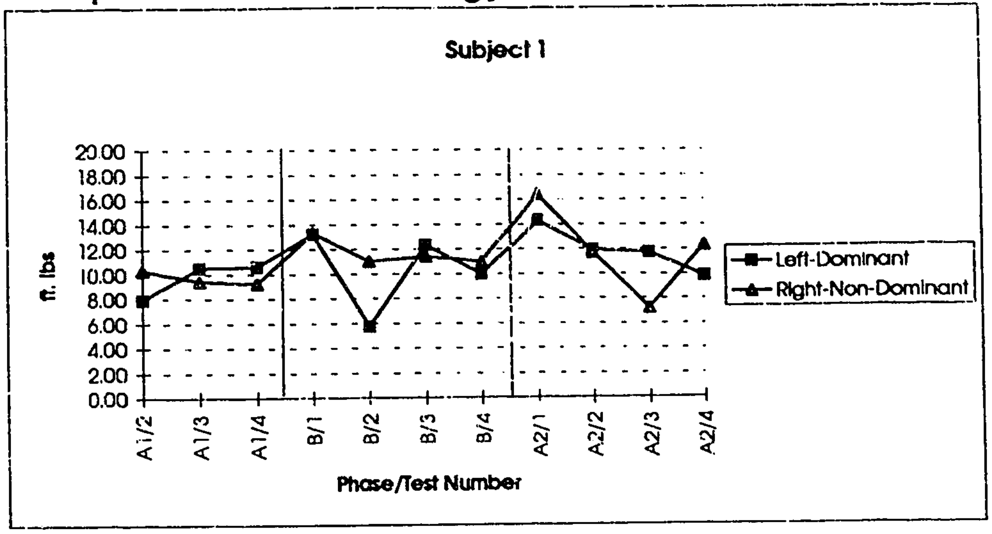
Torque Acceleration Energy Extension 4.19 rad·sec⁻¹

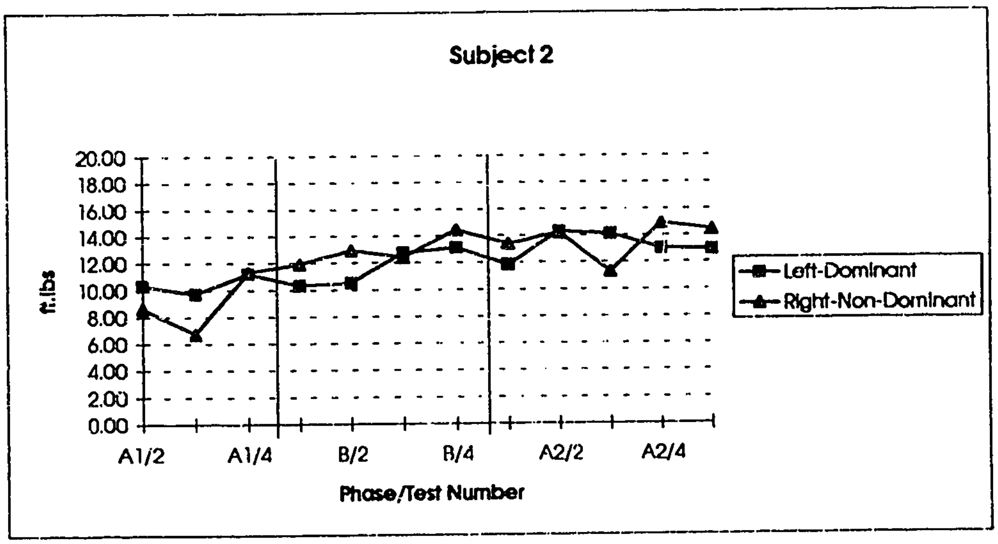


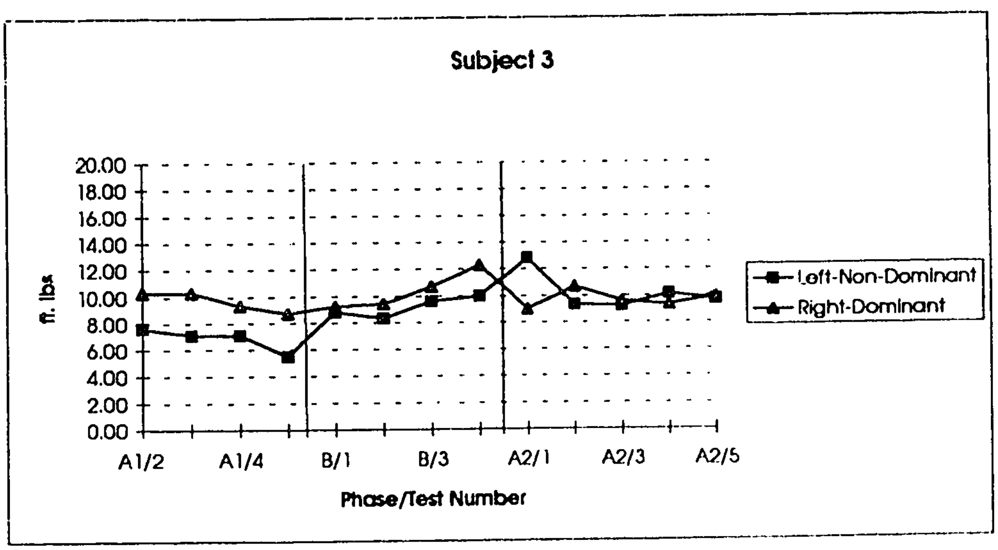


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Torque Acceleration Energy Flexion 5.24 rad·sec⁻¹

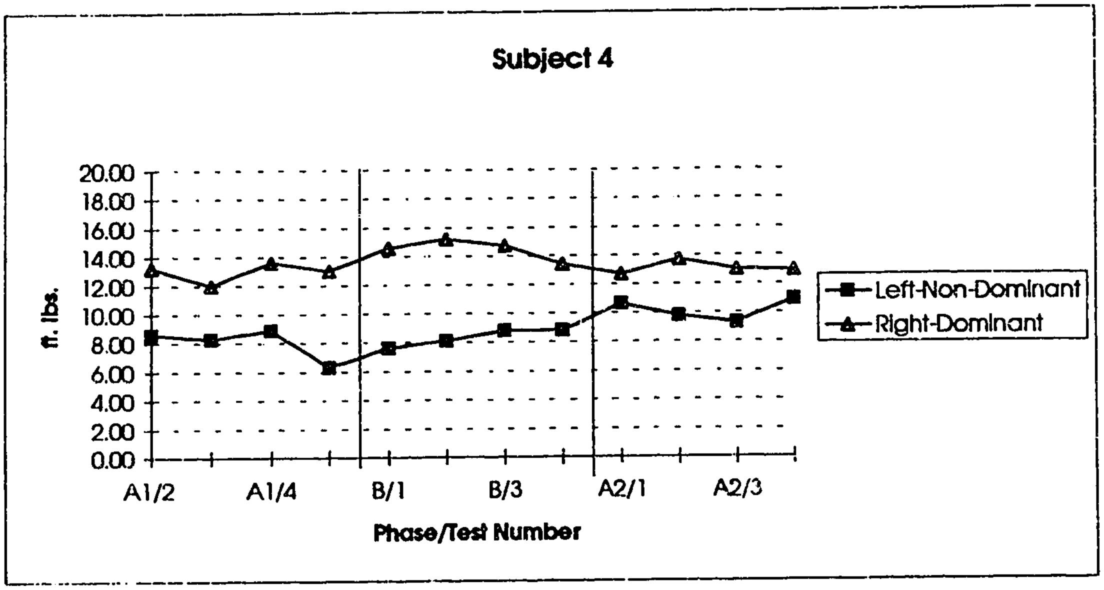


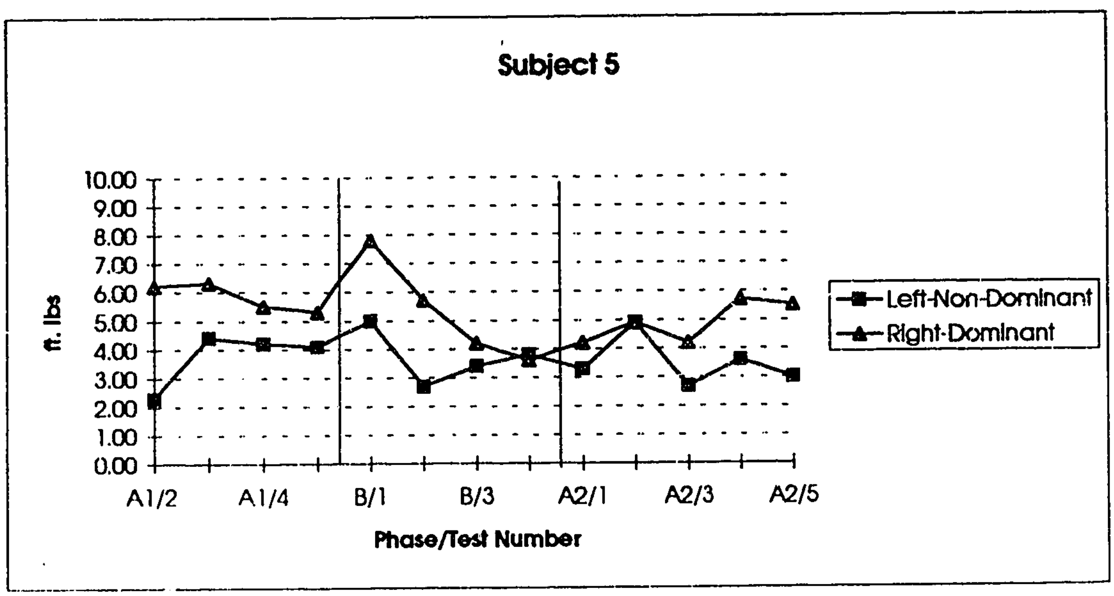




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

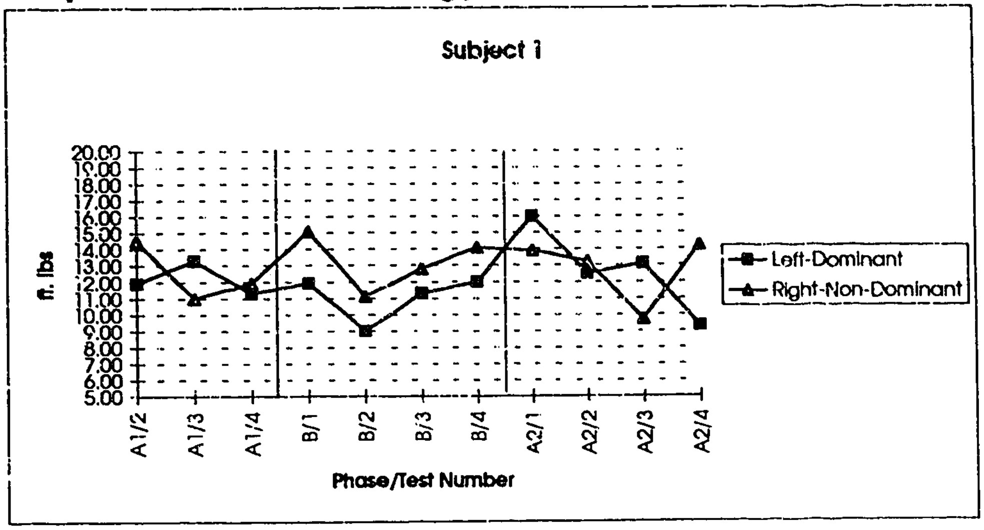
Torque Acceleration Energy Flexion 5.24 rad·sec^{-1}

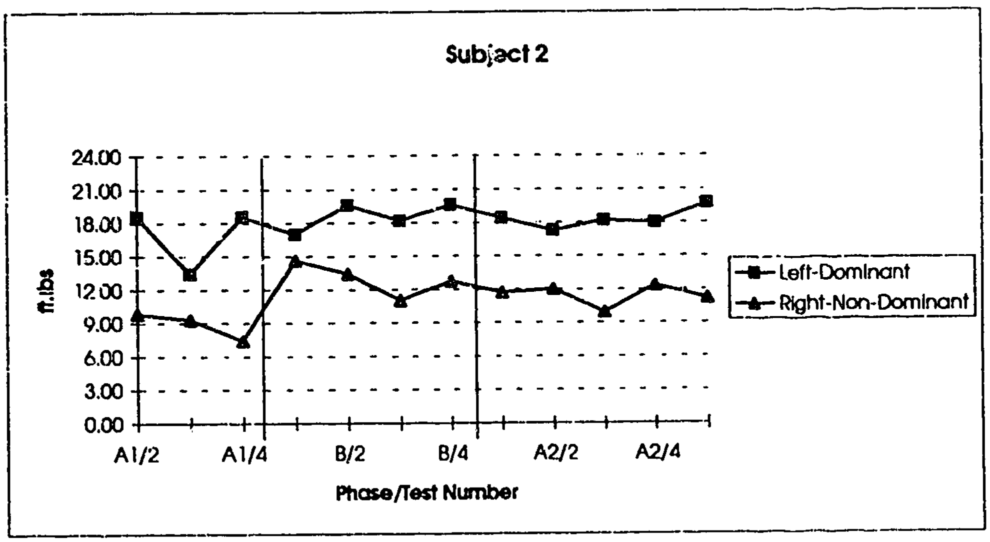


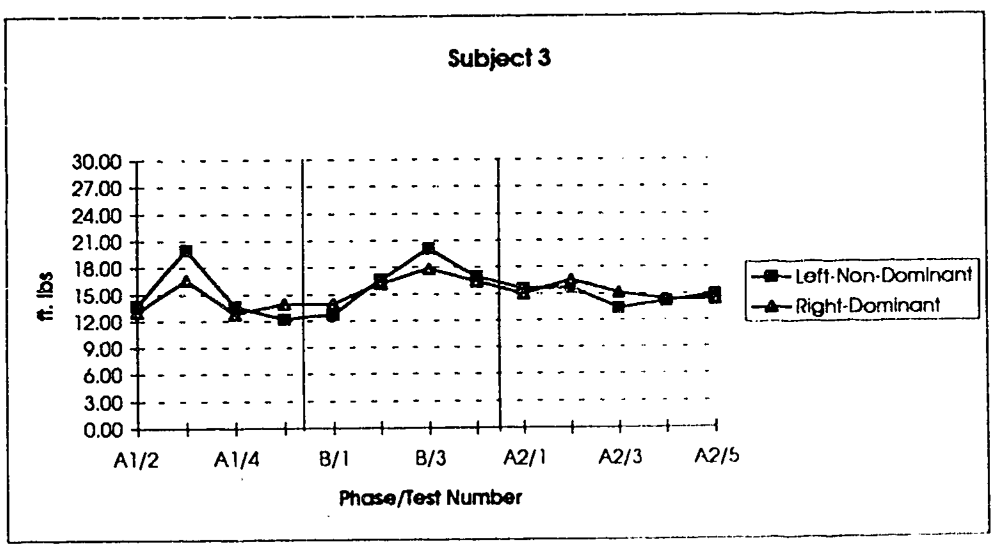


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Torque Acceleration Energy Extension 5.24 rad·sec^{-1}

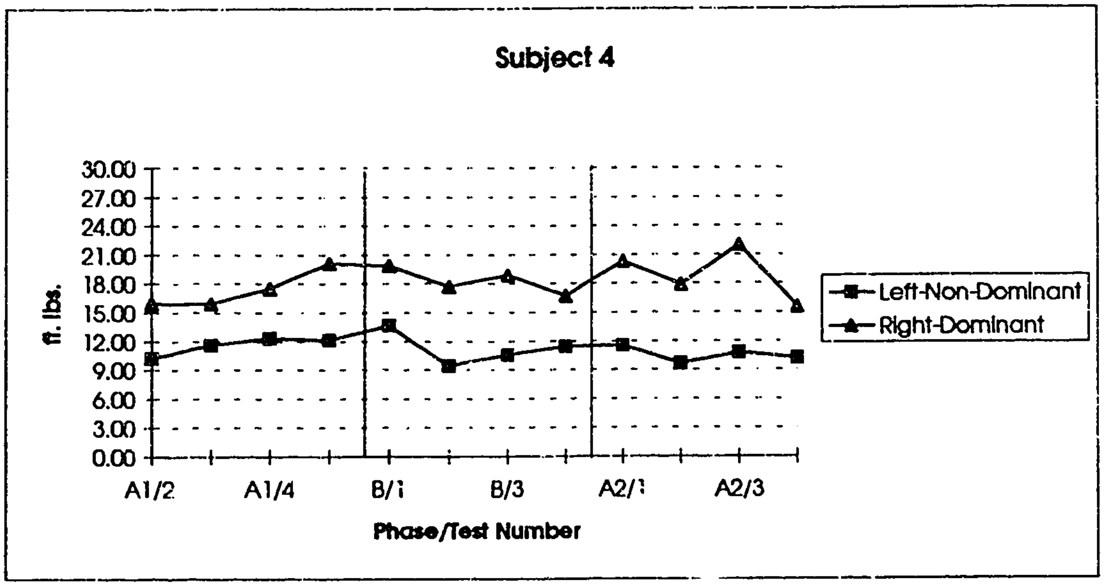


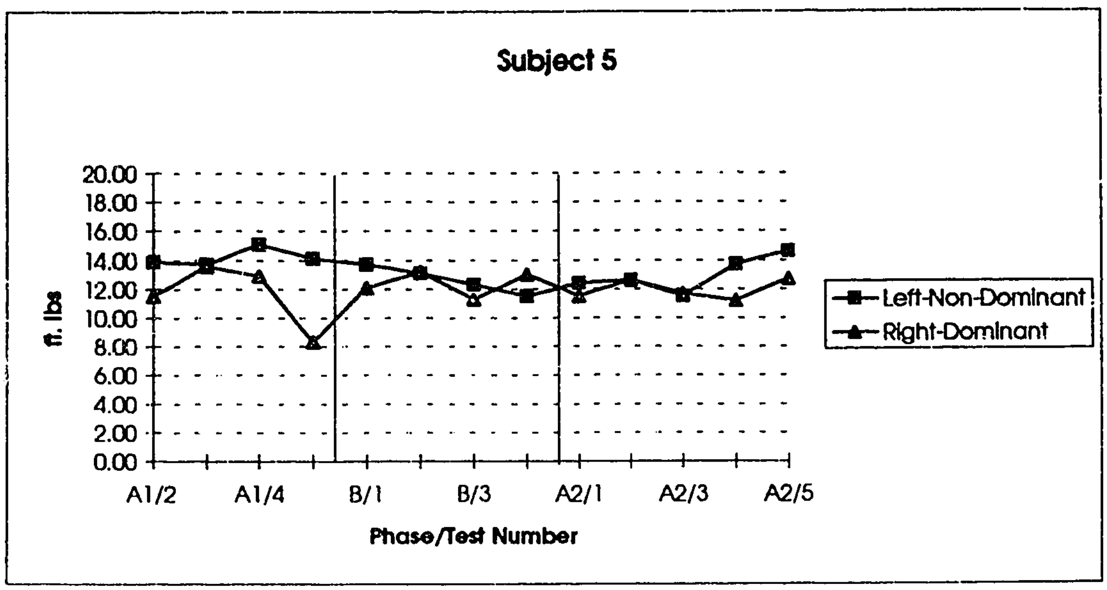




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

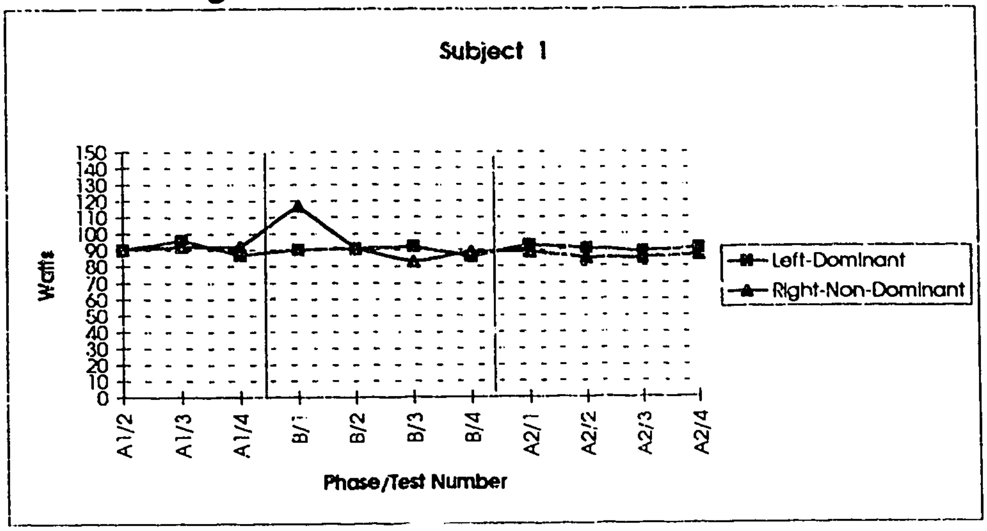
Torque Acceleration Energy Extension 5.24 rad·sec⁻¹

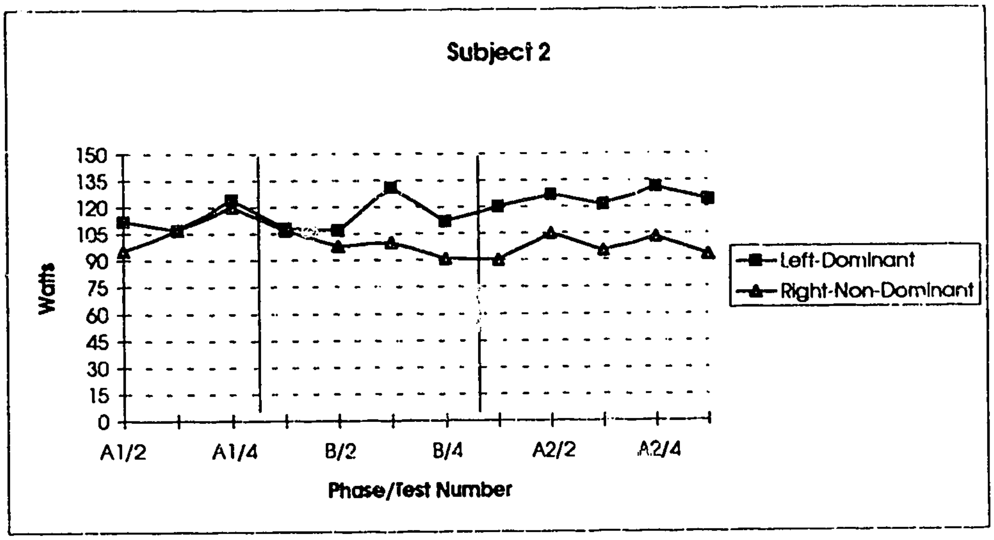


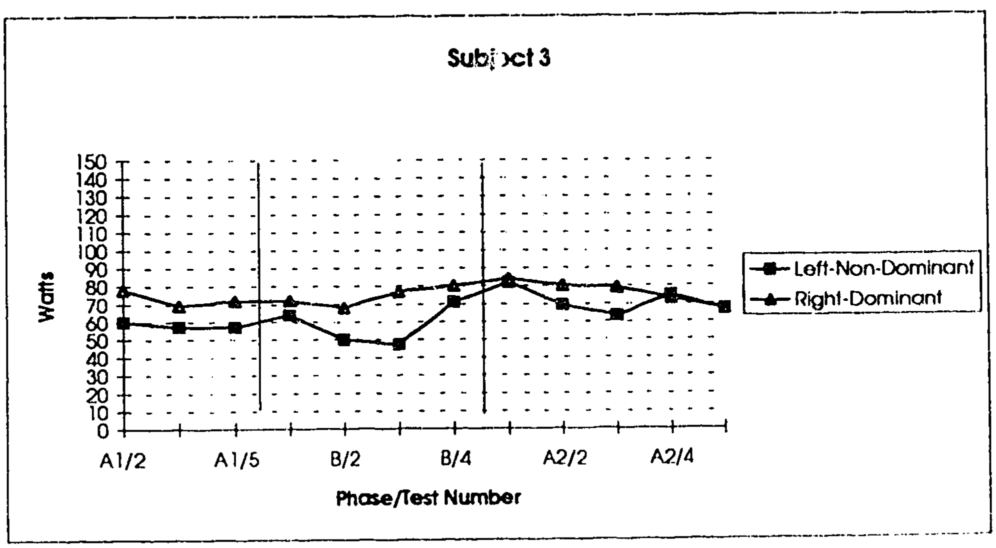


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Average Power Flexion - Endurance Test

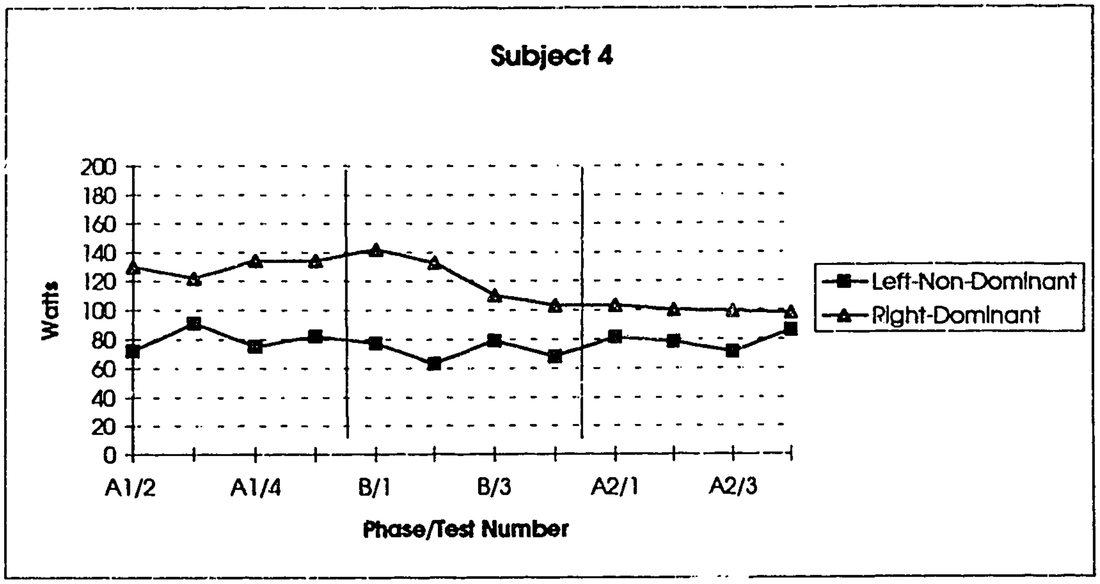


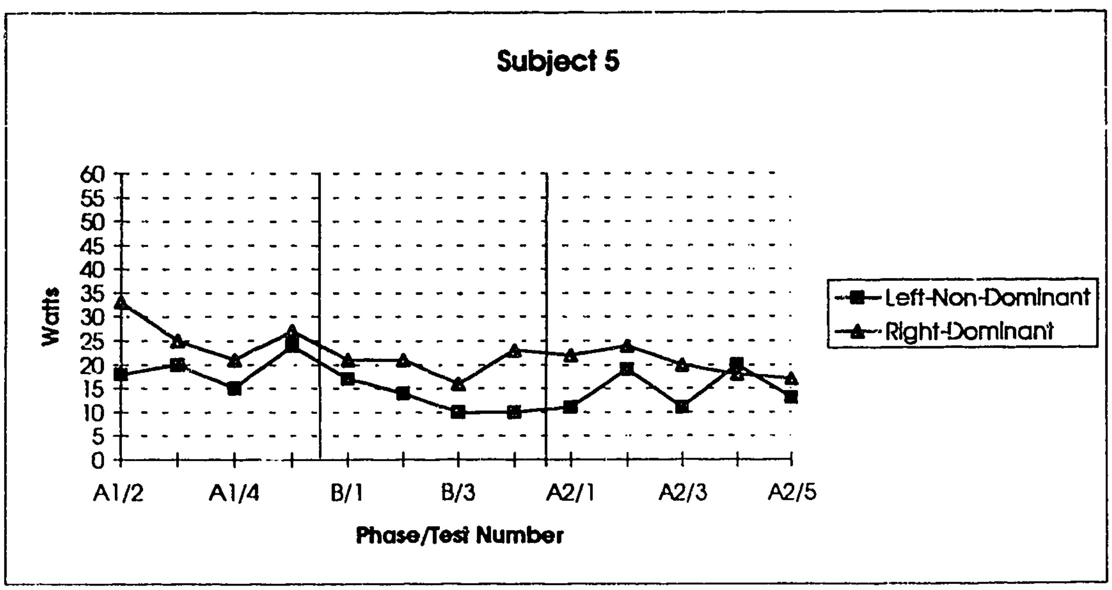




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

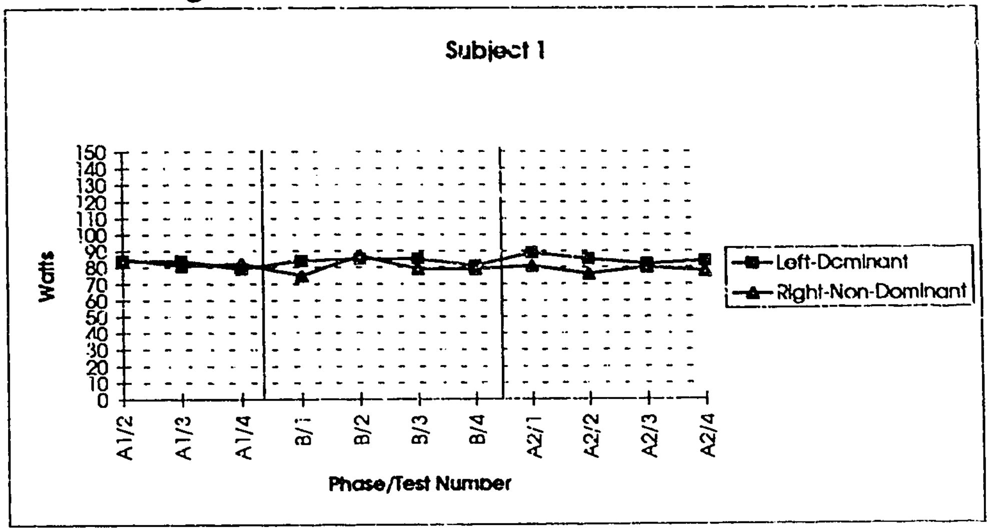
Average Power Flexion - Endurance Test

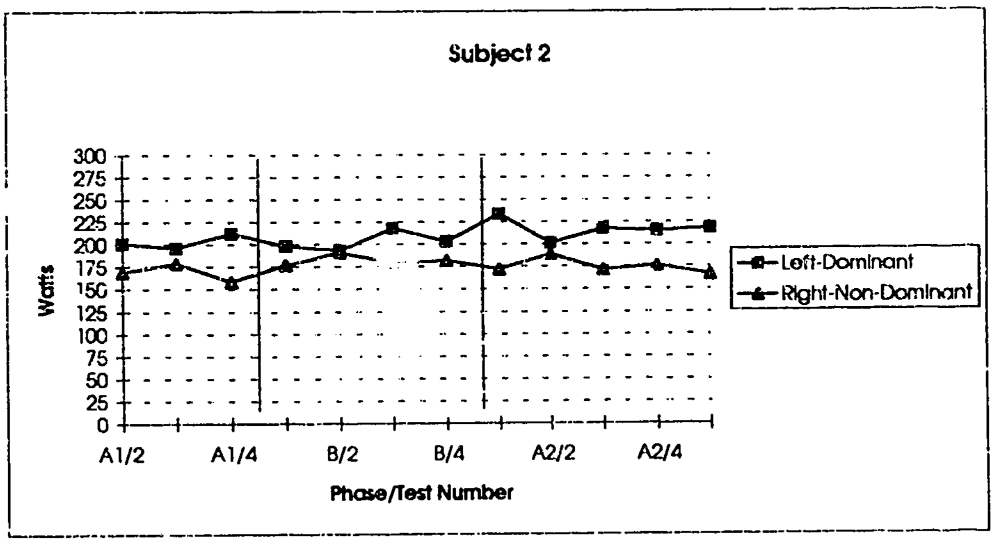


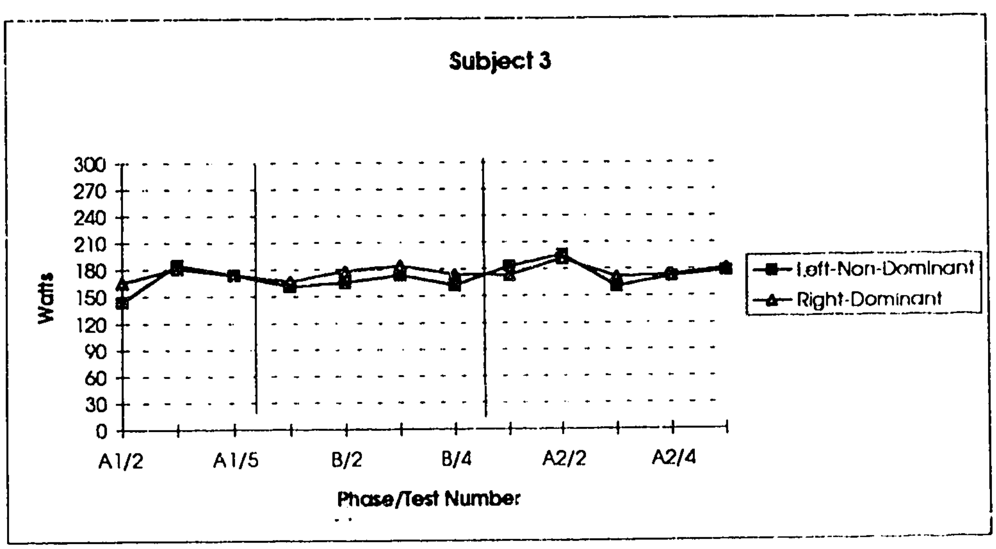


A1 - Baseline Phase   B - Intervention Phase   A2 - Withdrawal Phase

Average Power Extension - Endurance Test

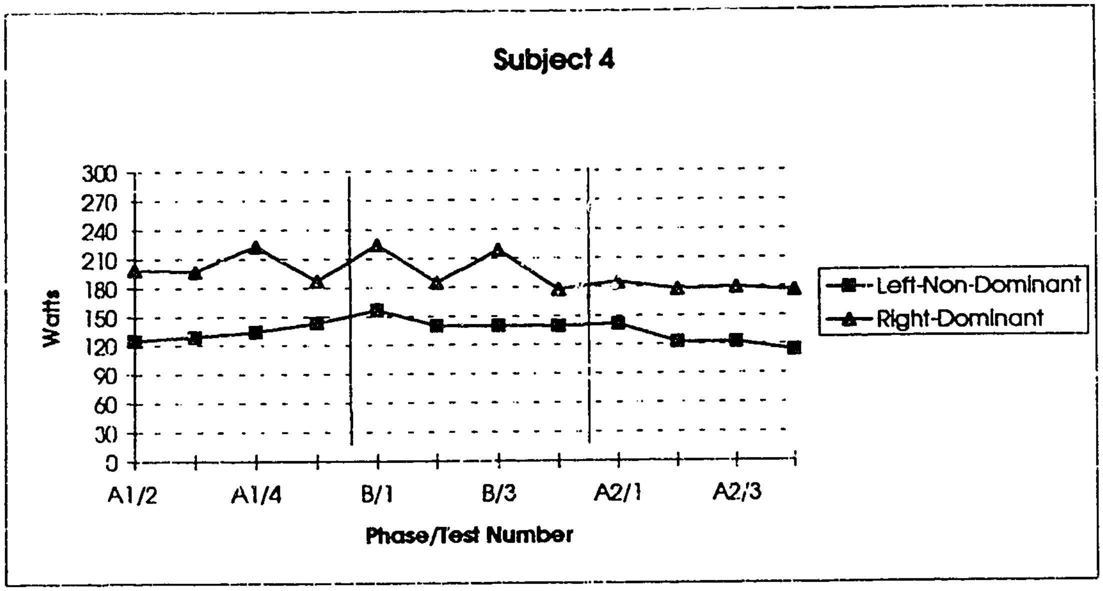


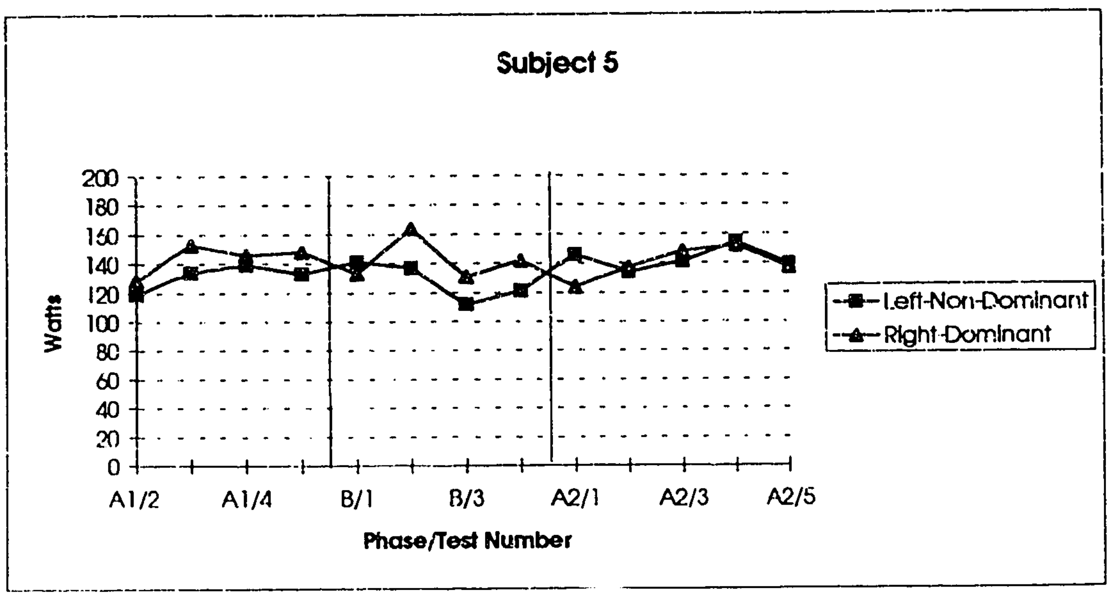




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

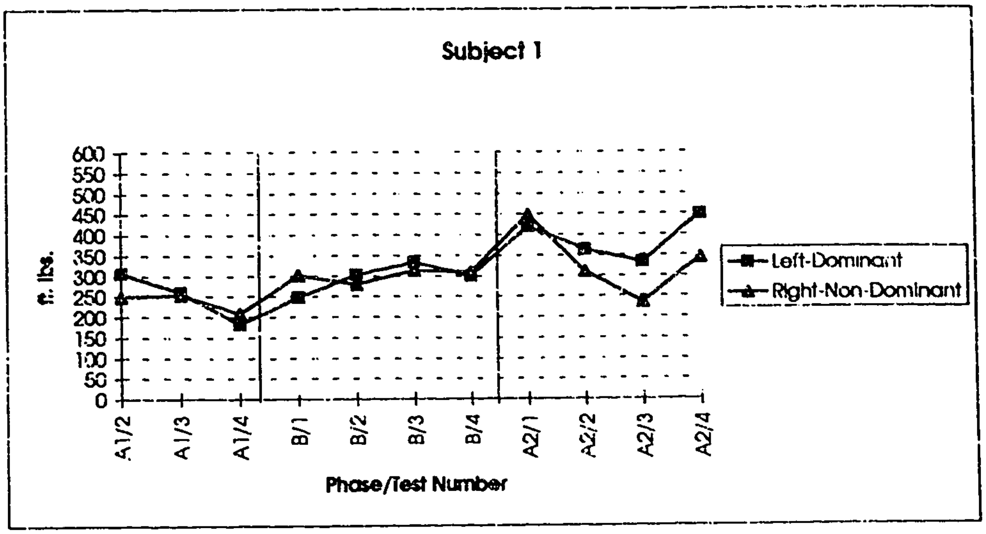
Average Power Extension - Endurance Test

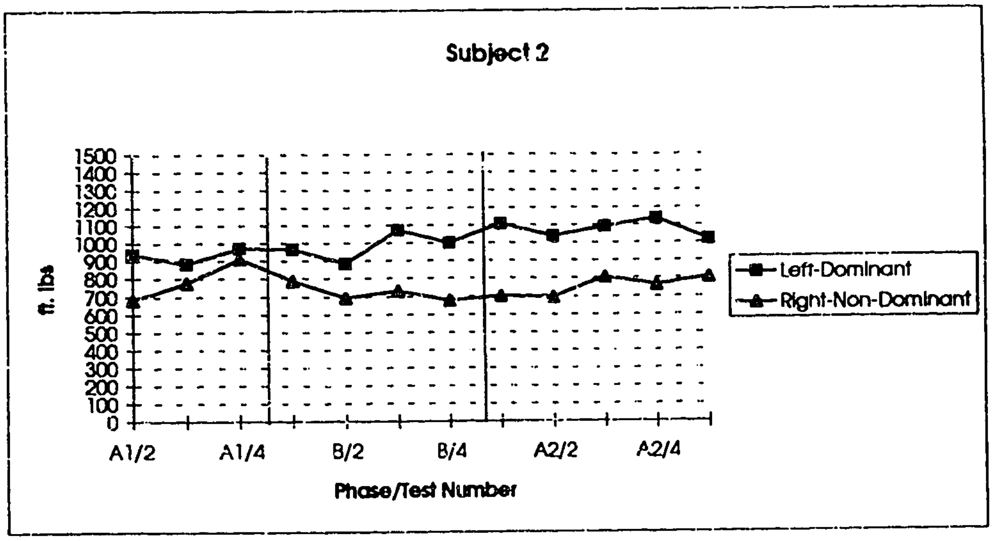


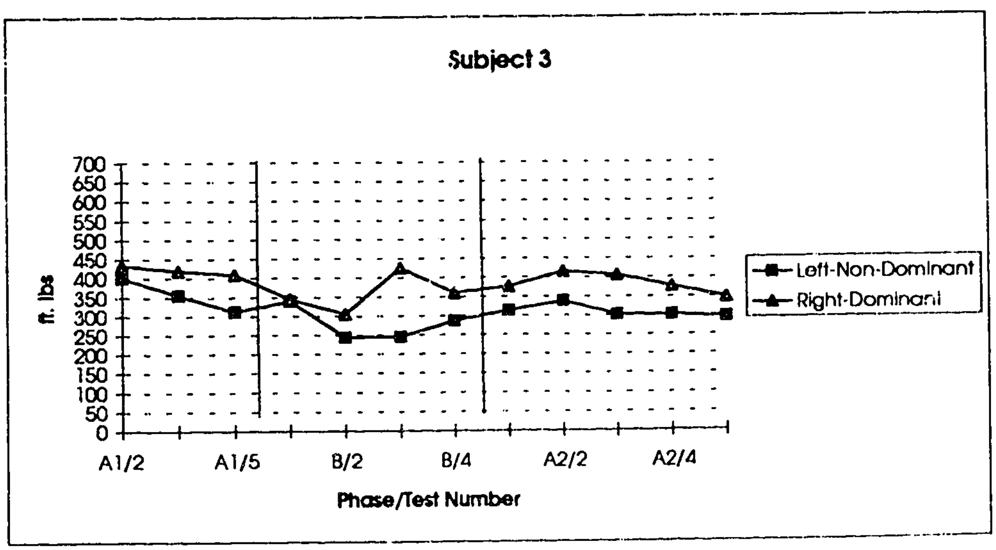


A1 - Baseline Phase   B - Intervention Phase   A2 - Withdrawal Phase

Total Work Flexion - Endurance Test

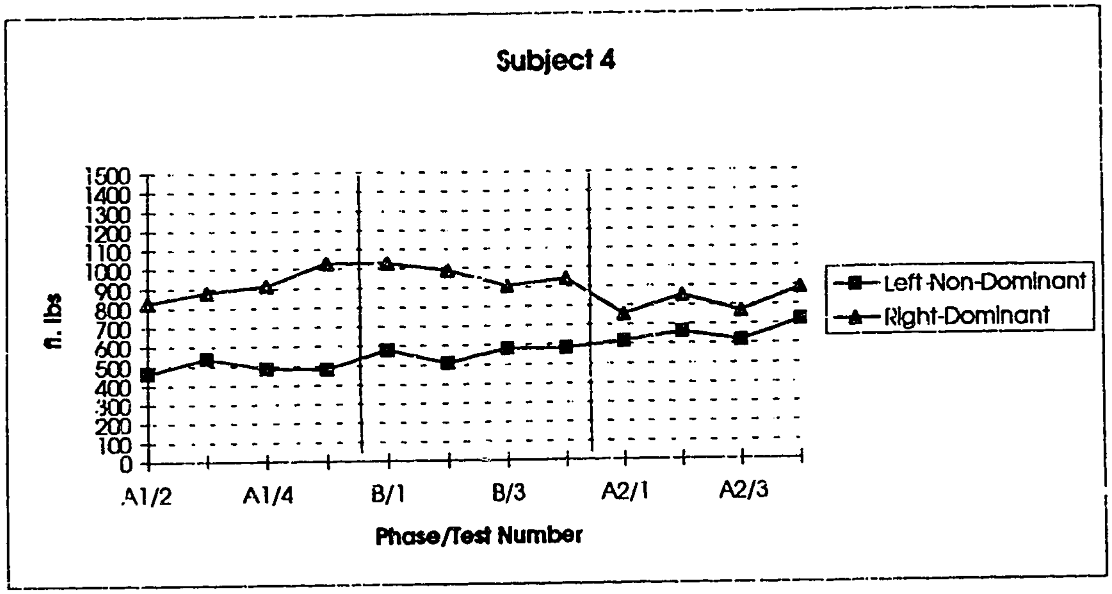


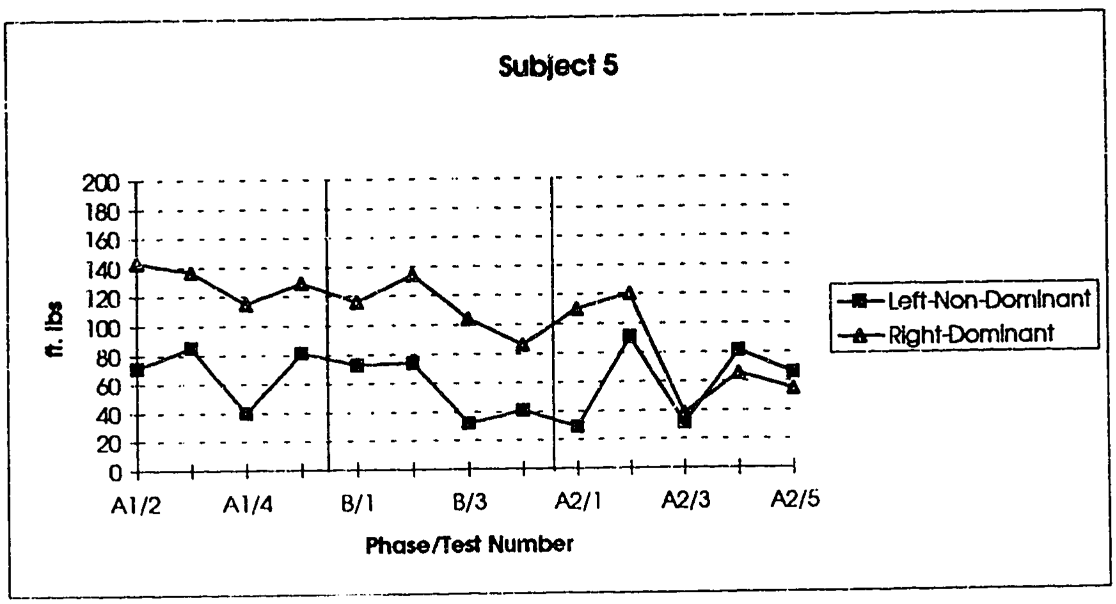




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

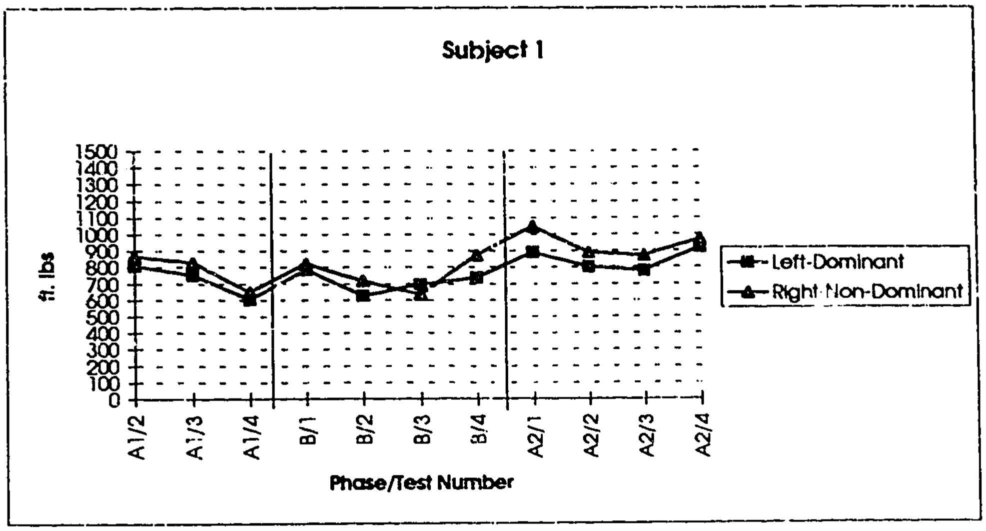
Total Work Flexion - Endurance Test

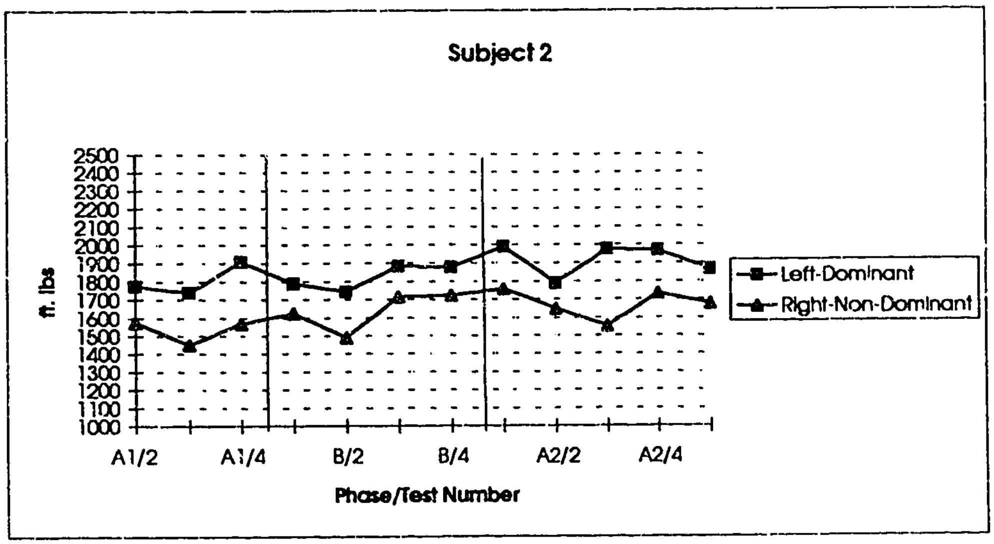


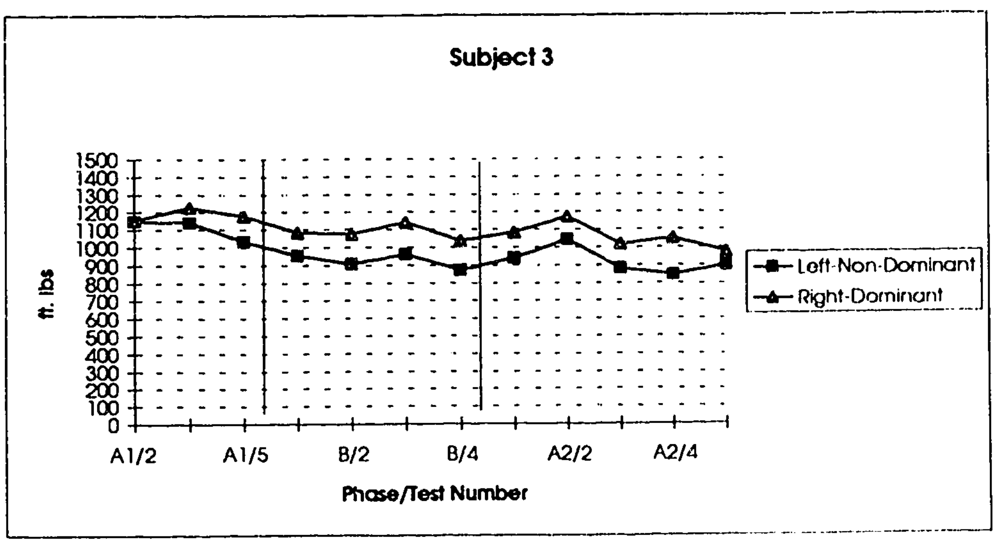


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Total Work Extension - Endurance Test

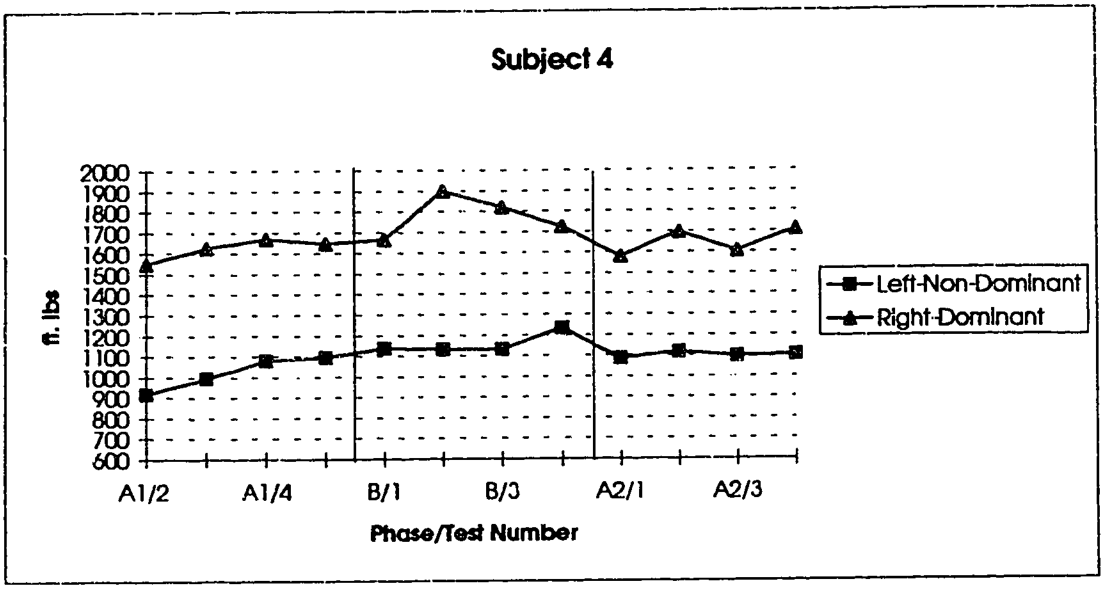


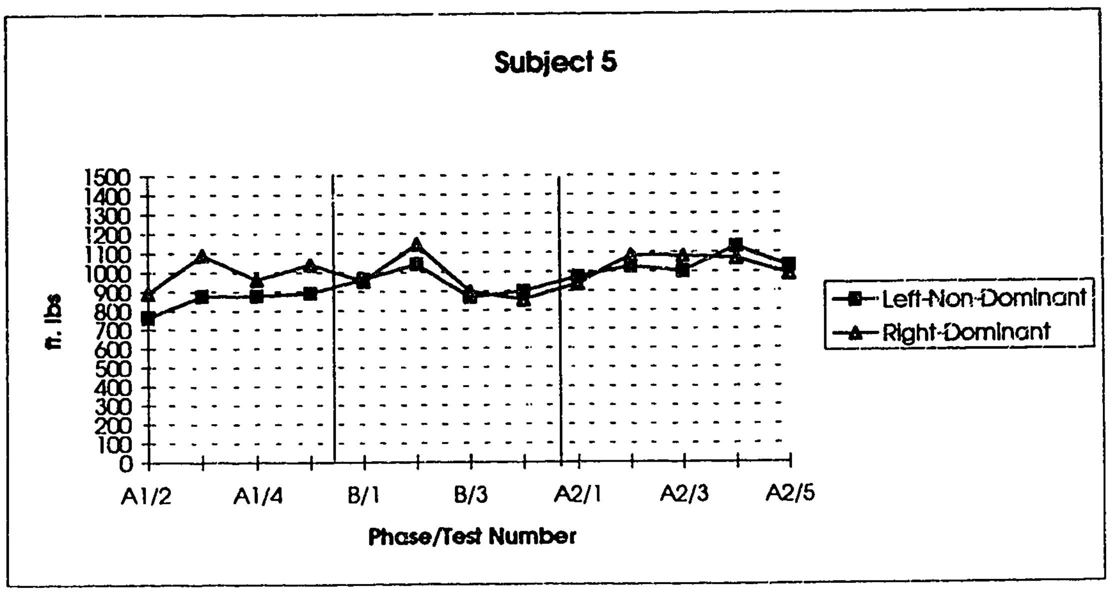




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

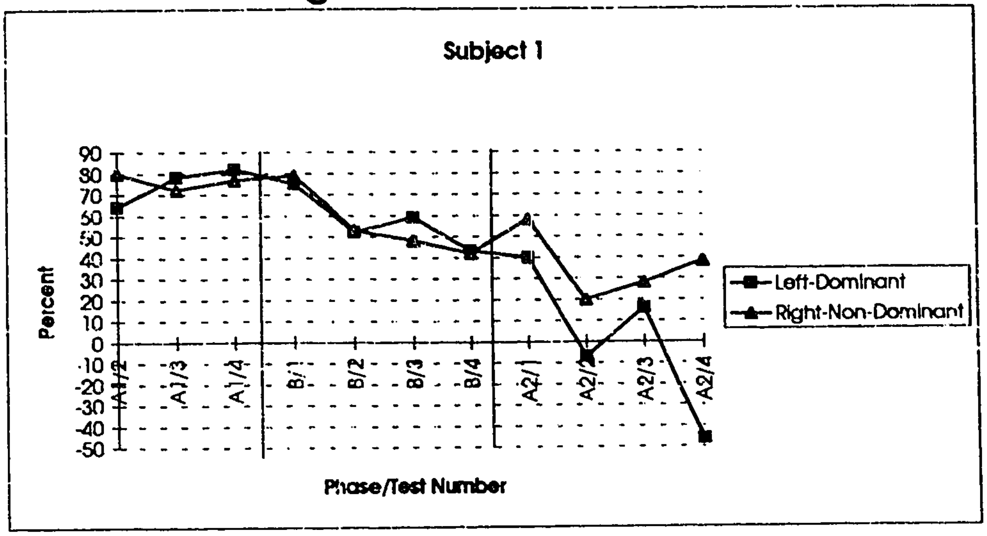
Total Work Extension - Endurance Test

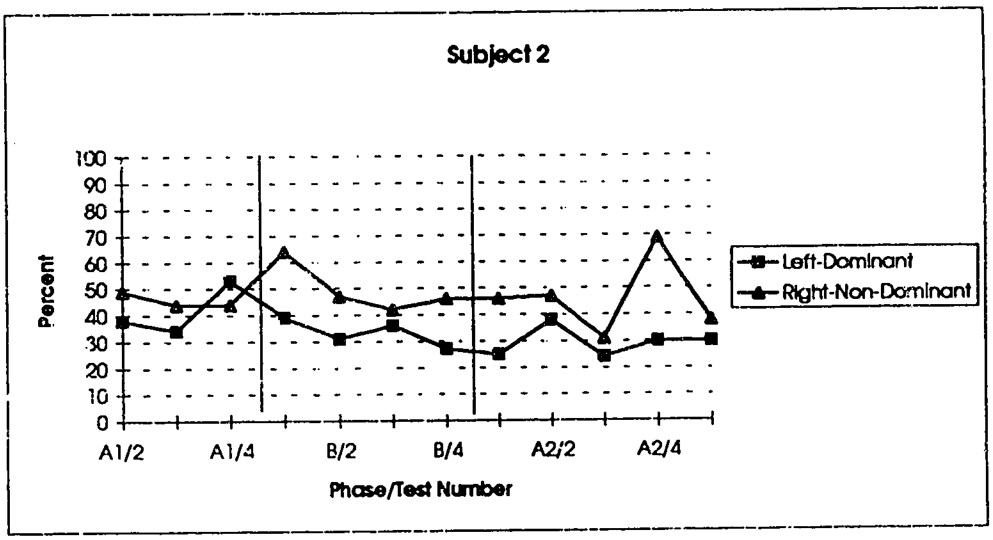


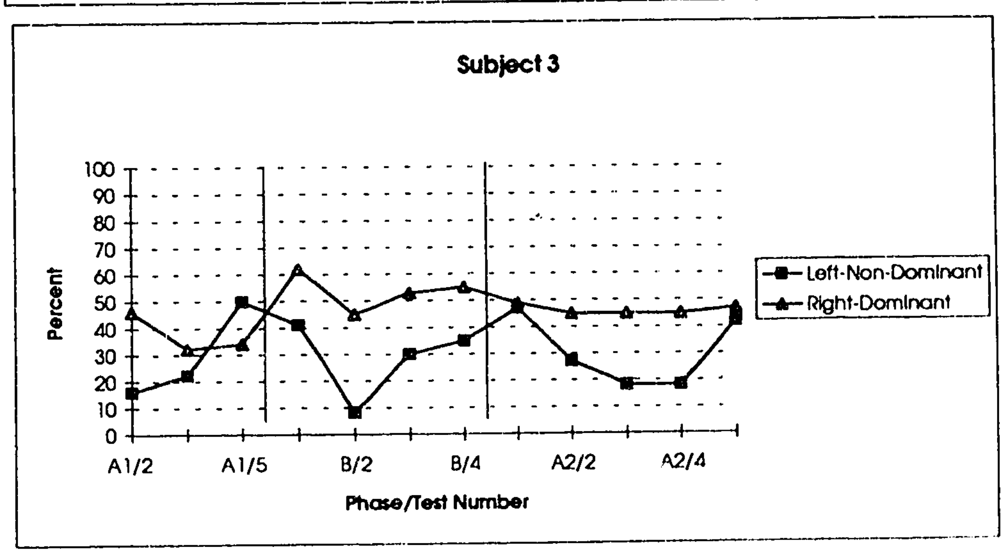


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Percent Fatigue Flexion - Endurance Test

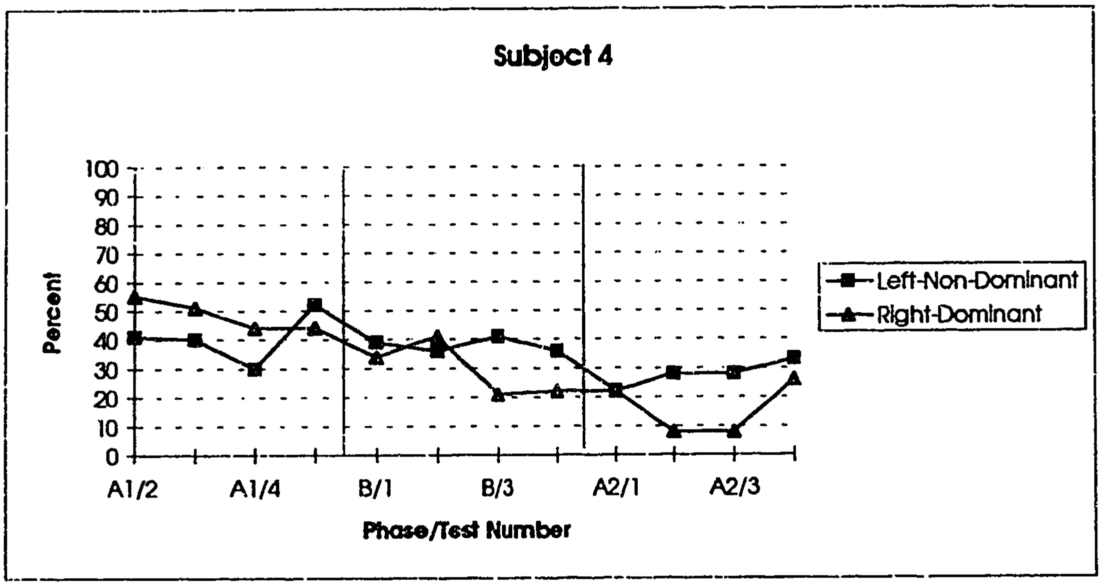


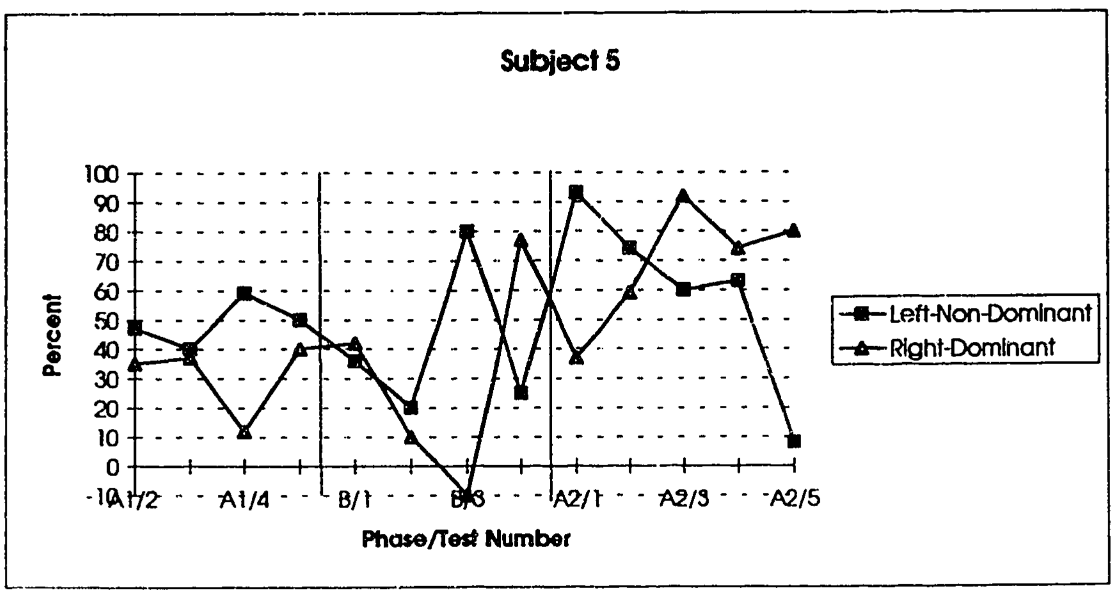




A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

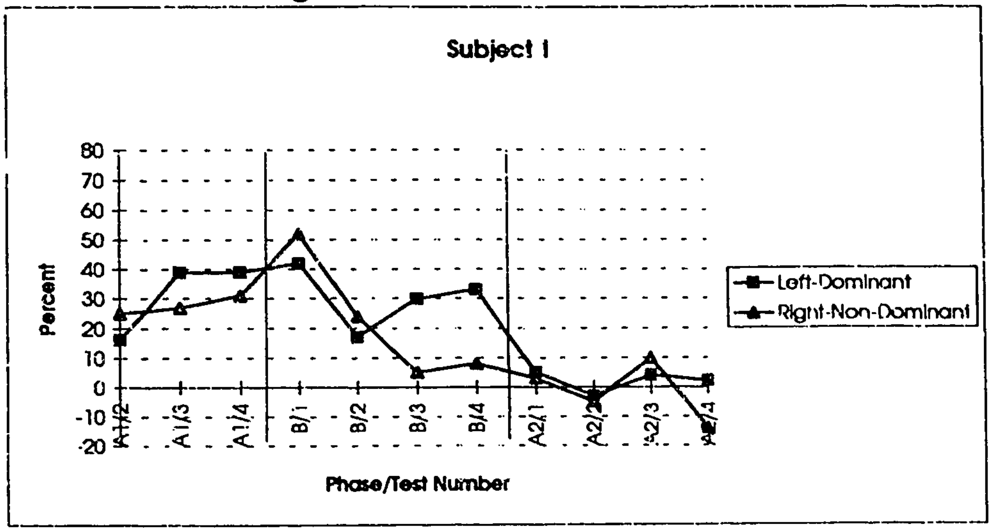
Percent Fatigue Flexion - Endurance Test

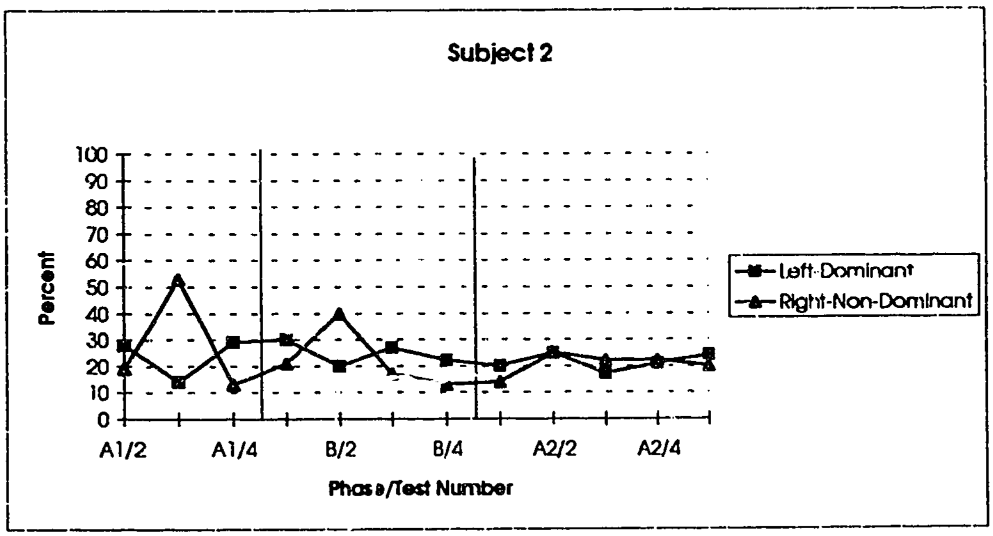


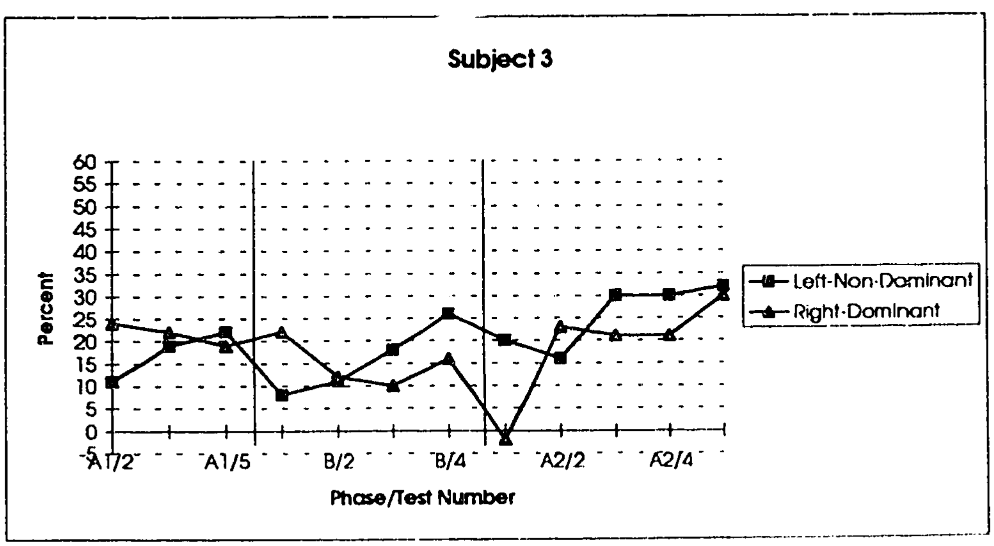


A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

Percent Fatigue Extension - Endurance Test

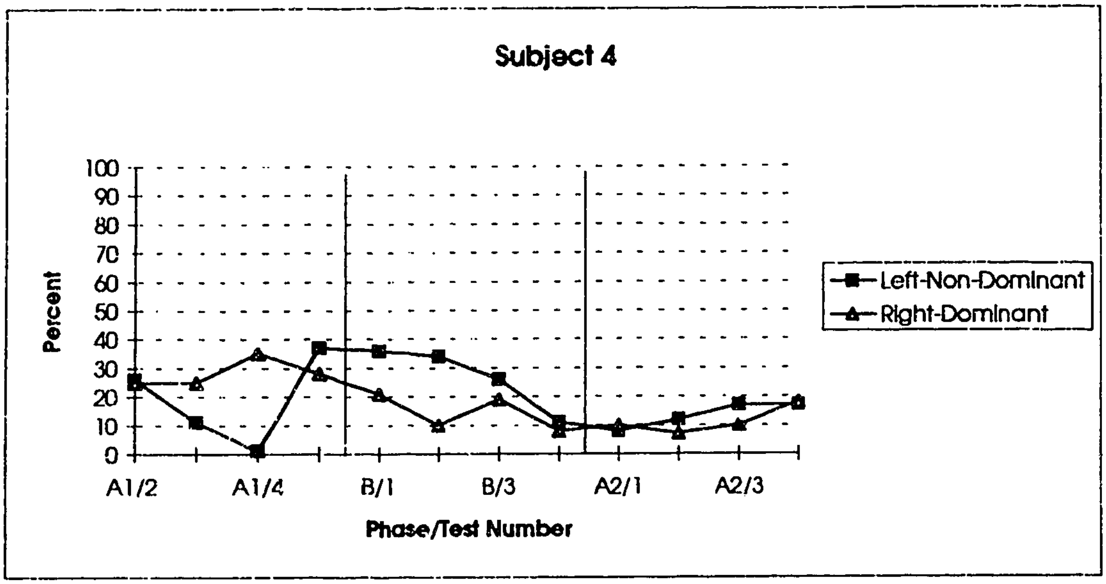


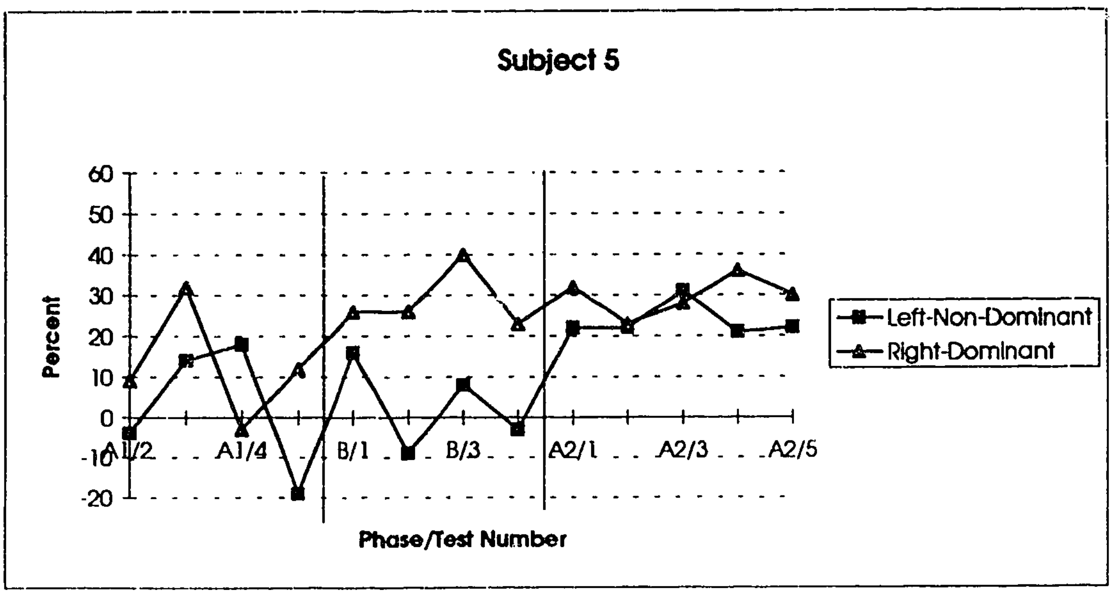




A1 - Baseline Phase   B - Intervention Phase   A2 - Withdrawal Phase

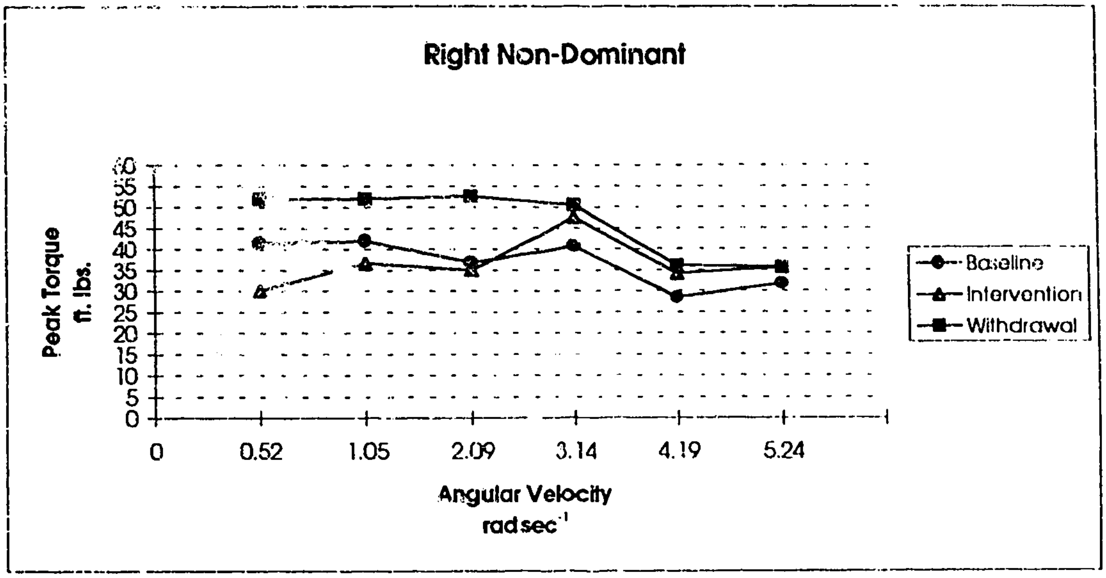
Percent Fatigue Extension - Endurance Test

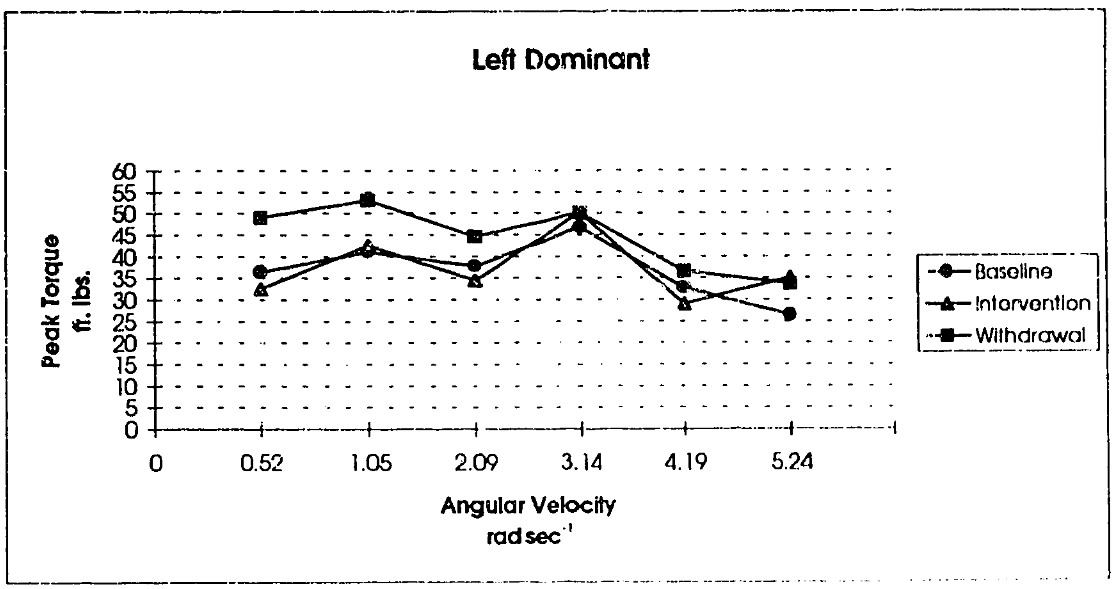




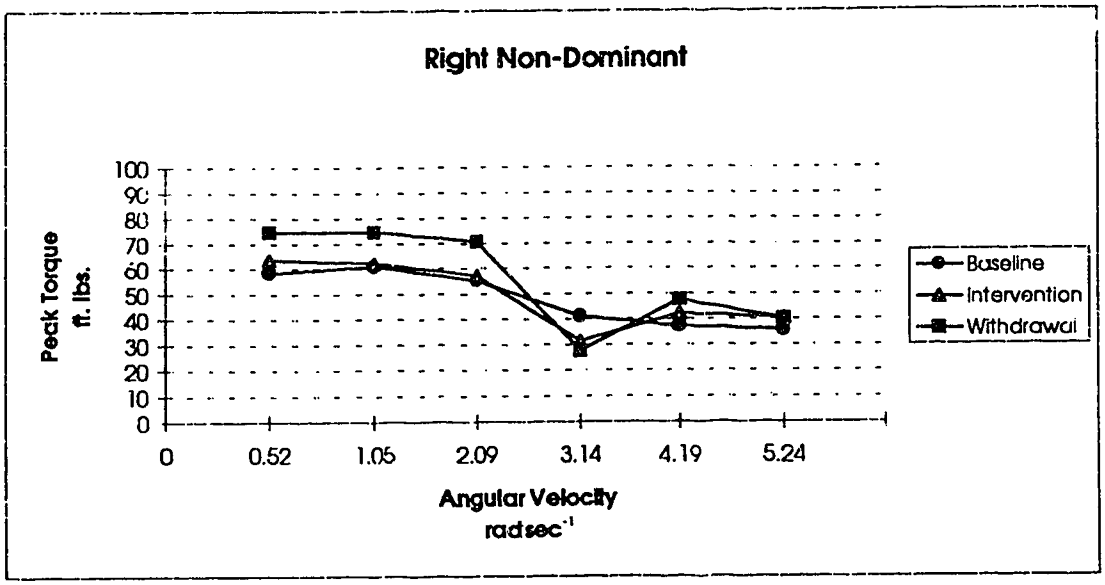
A1 - Baseline Phase B - Intervention Phase A2 - Withdrawal Phase

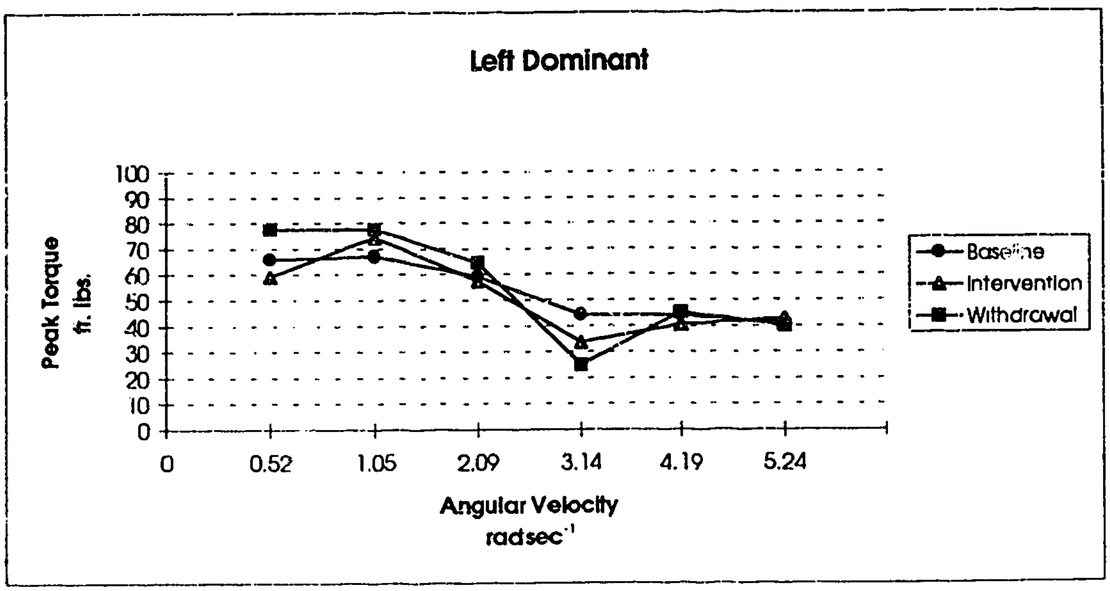
Peak Torque vs Angular Velocity Flexion
Subject #1



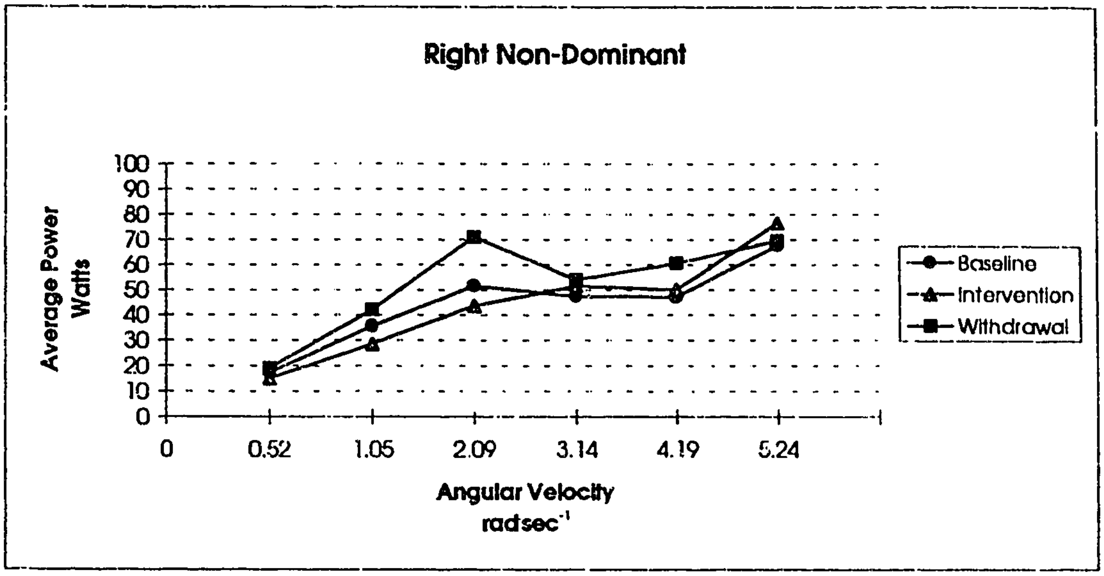


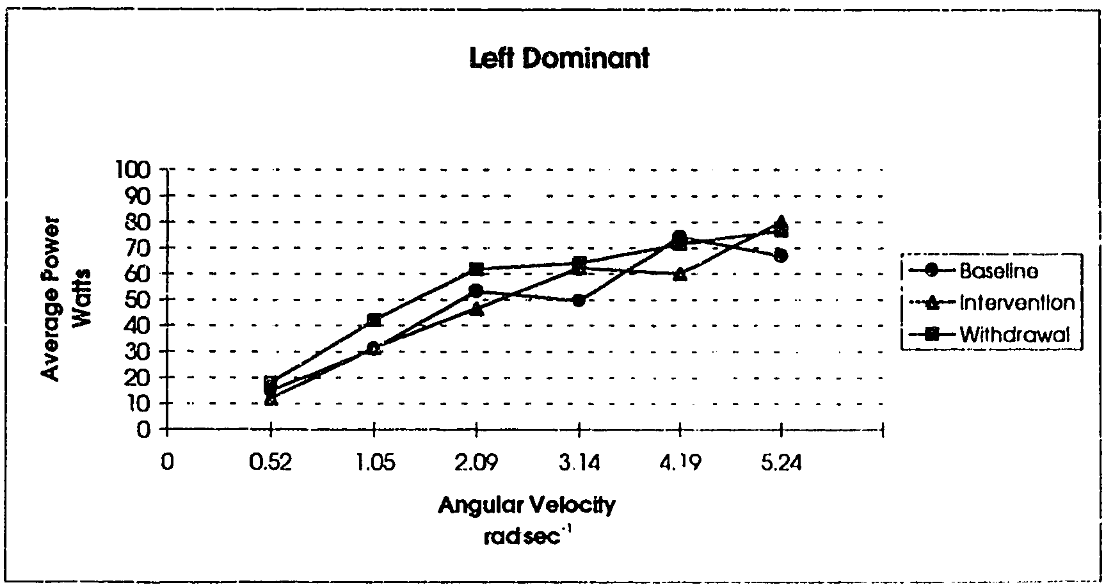
Peak Torque vs Angular Velocity Extension
Subject #1



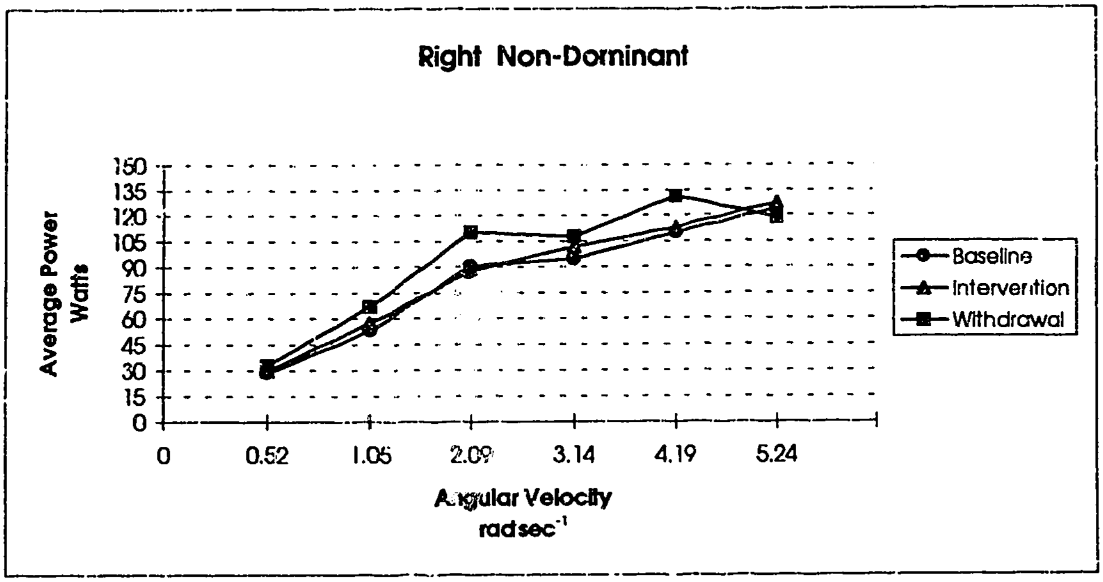


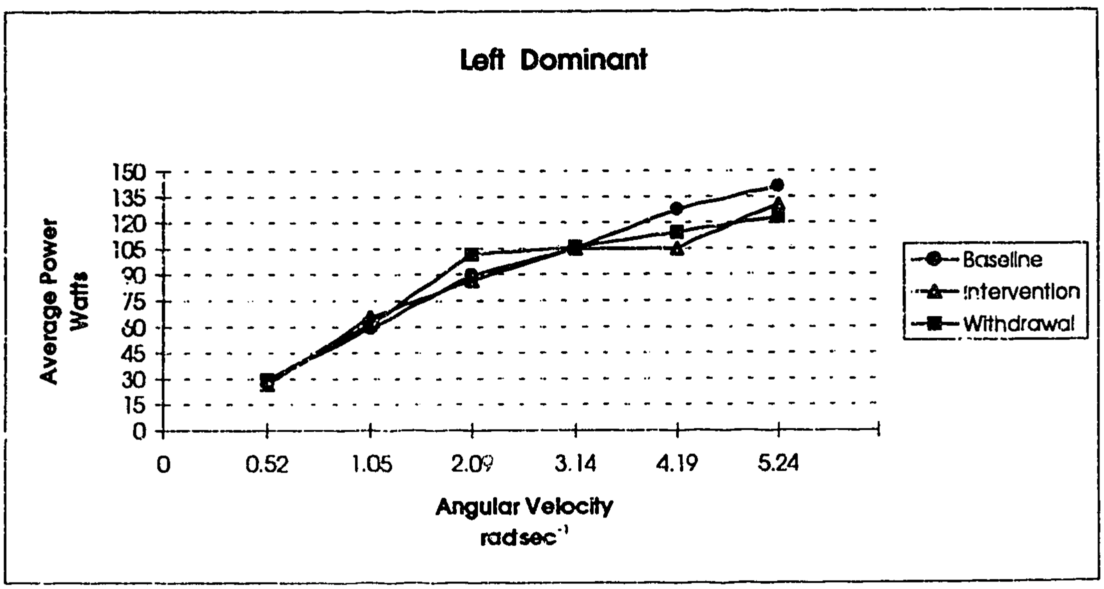
Average Power vs Angular Velocity Flexion
Subject #1



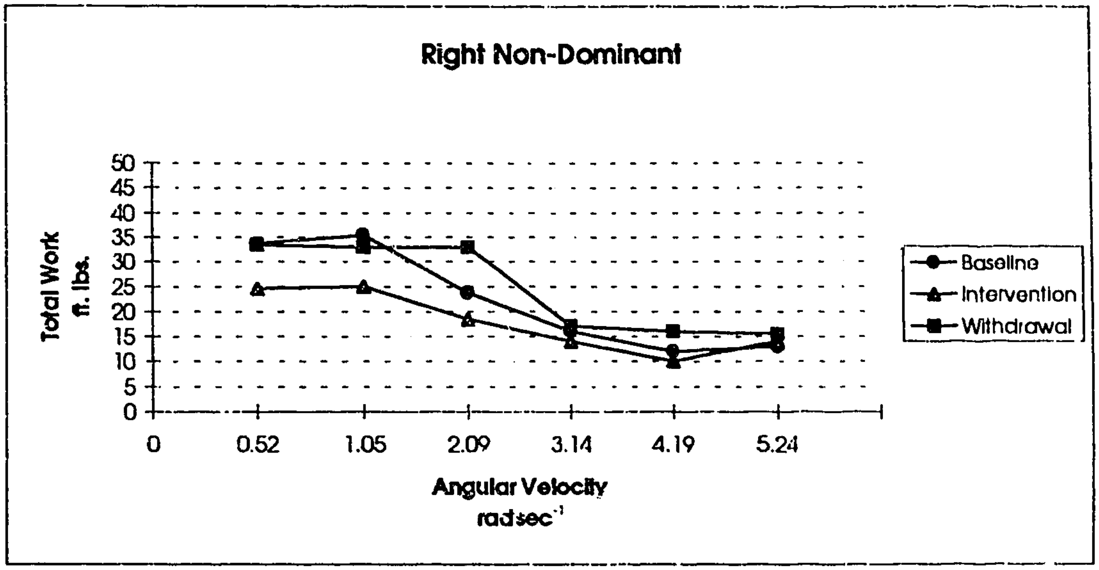


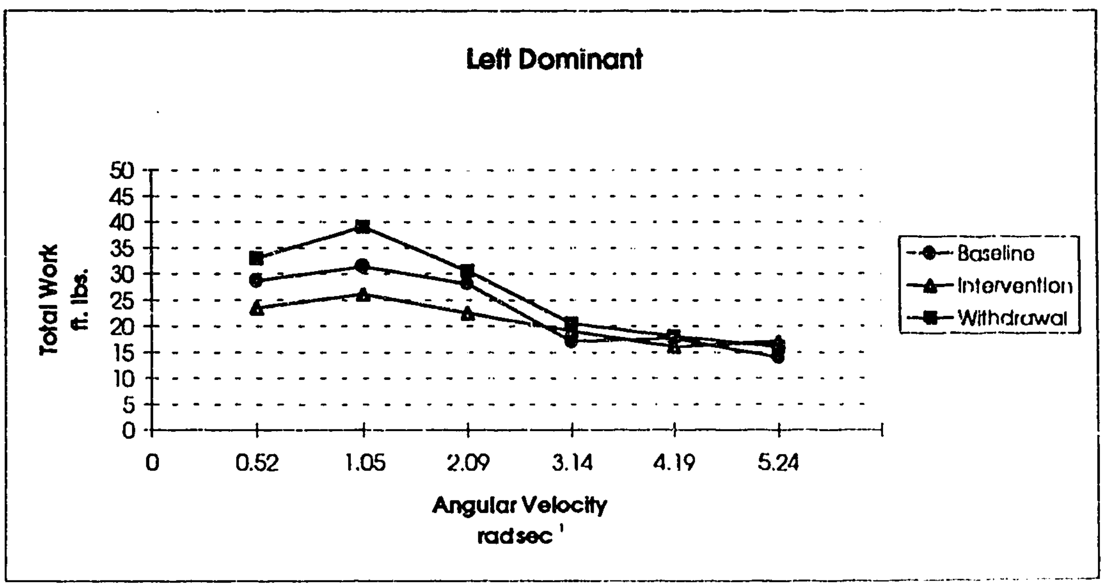
Average Power vs Angular Velocity Extension
Subject #1



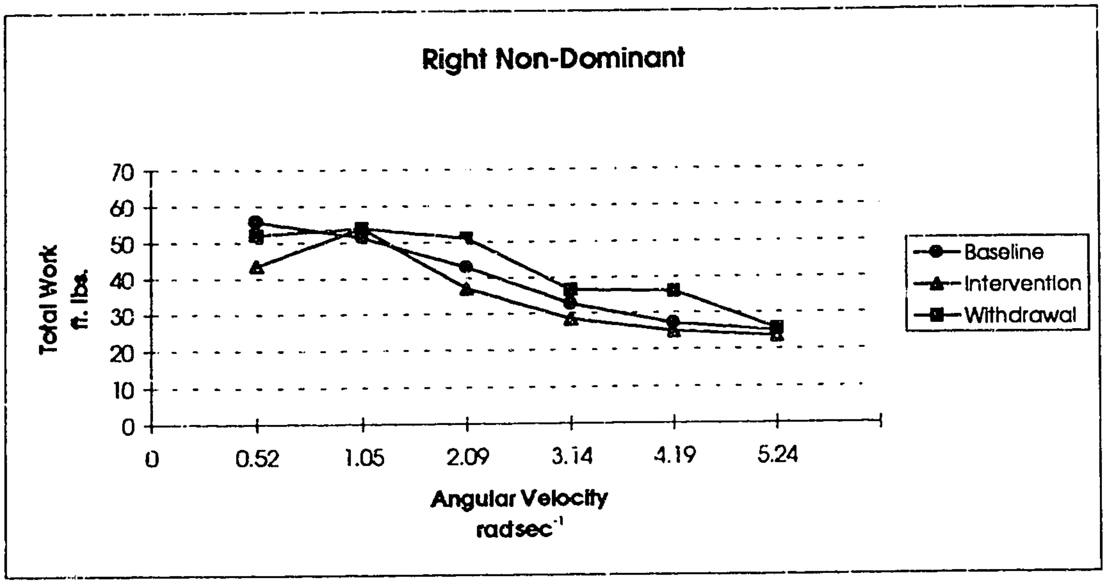


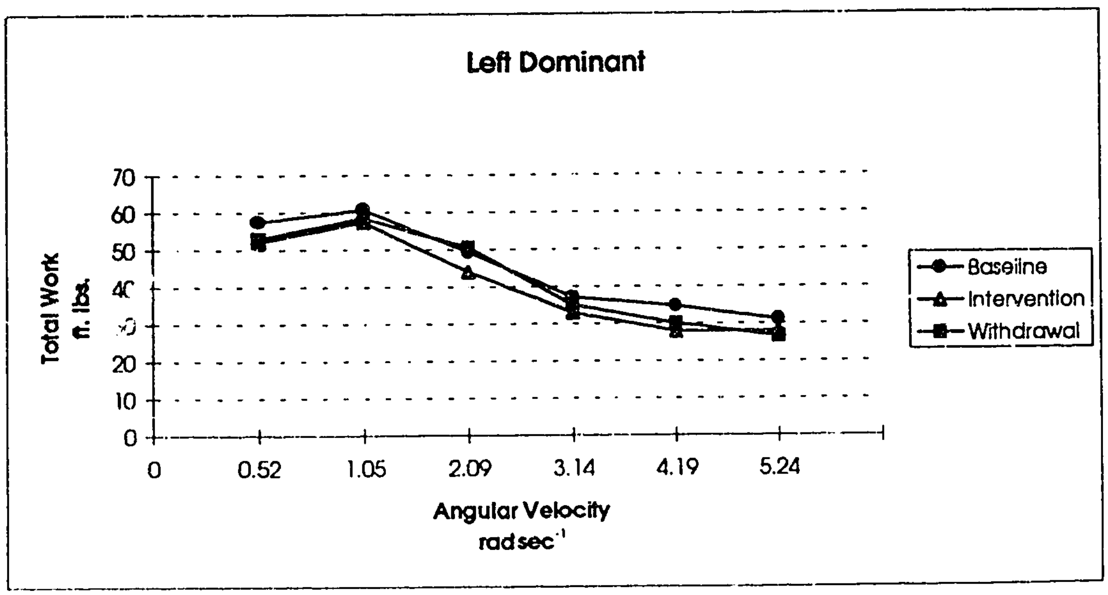
Total Work vs Angular Velocity Flexion
Subject #1



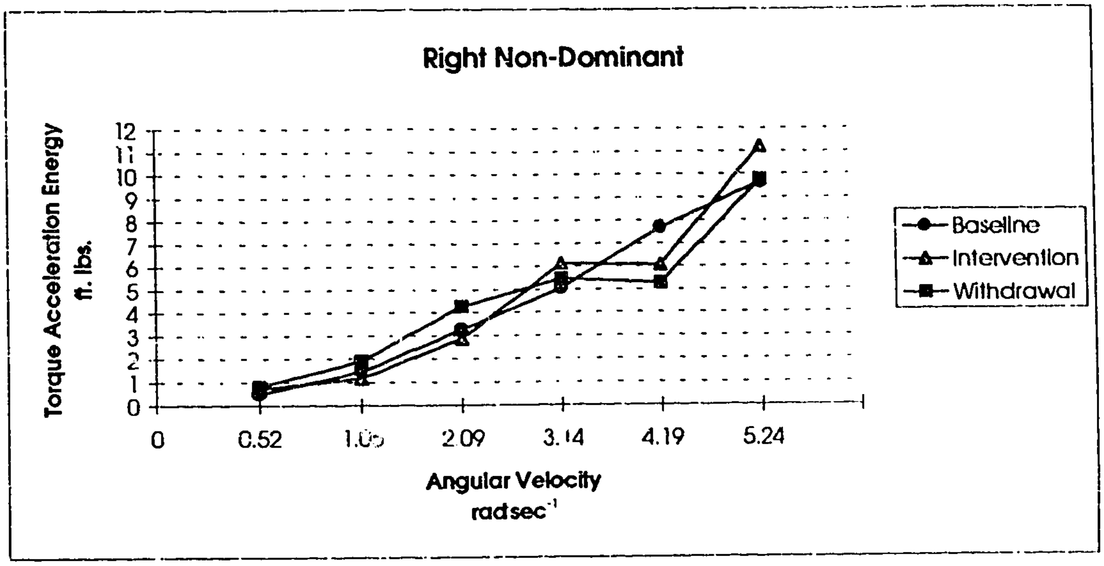


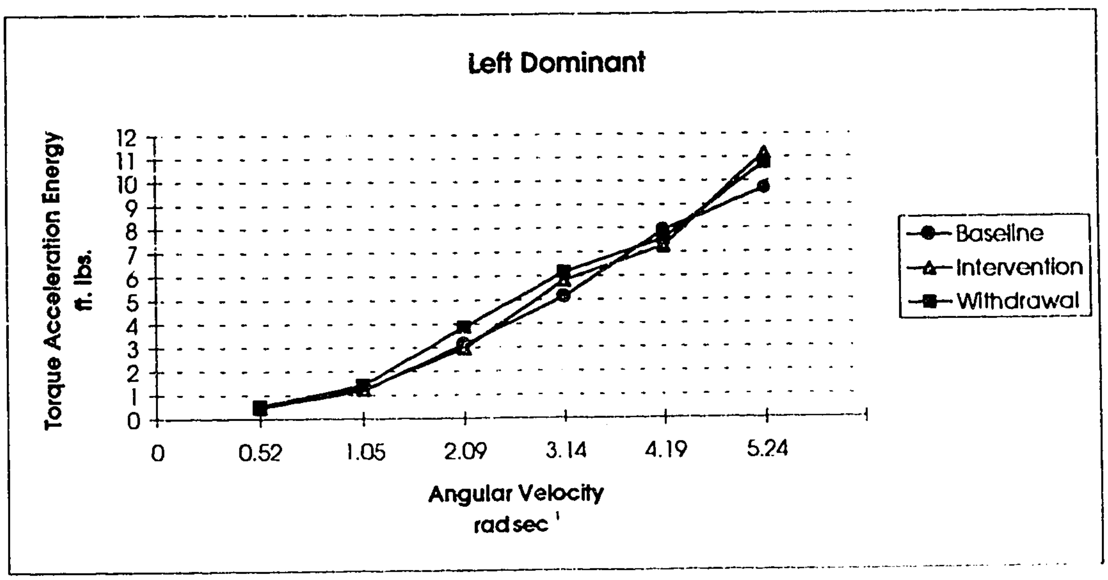
Total Work vs Angular Velocity Extension
Subject #1



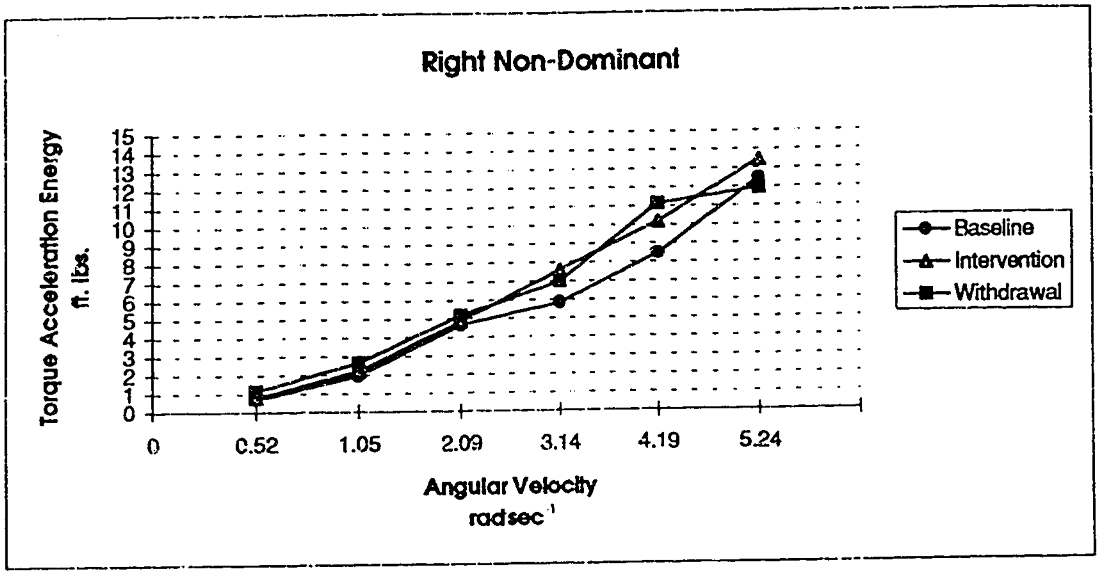


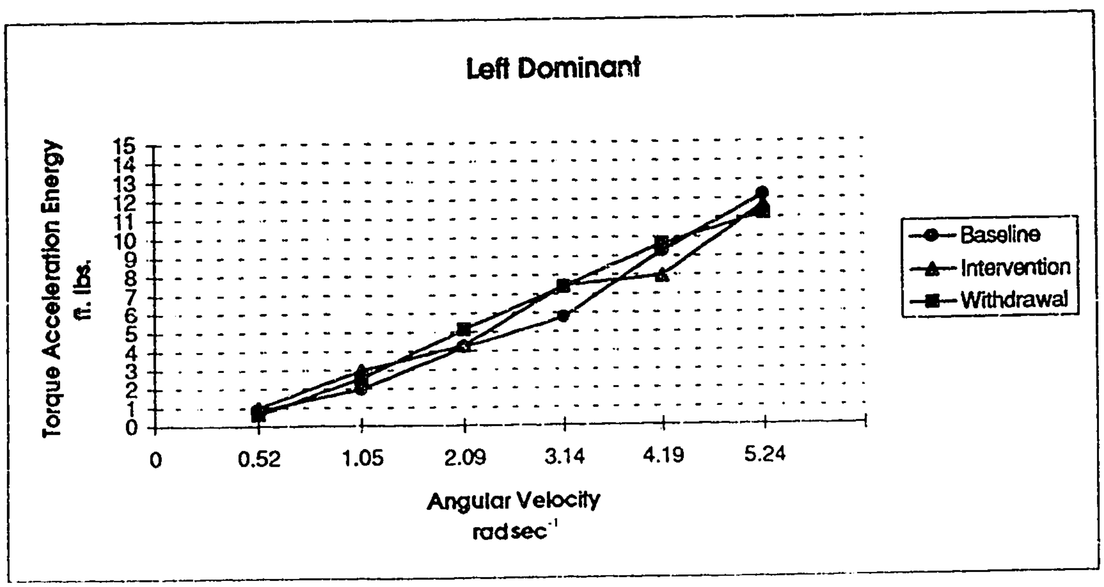
Torque Acceleration Energy vs Angular Velocity Flexion Subject #1



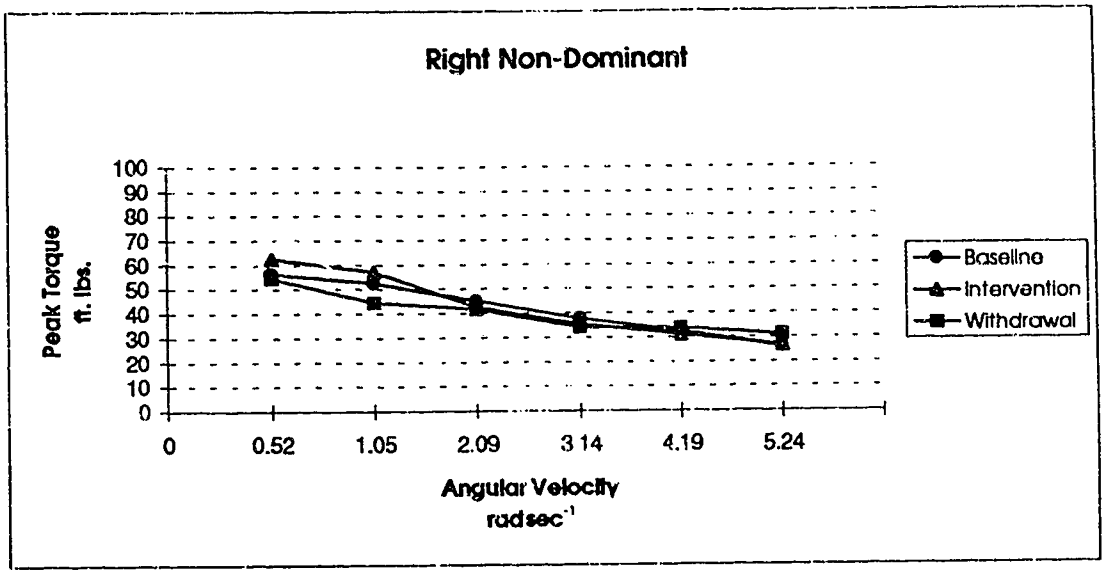


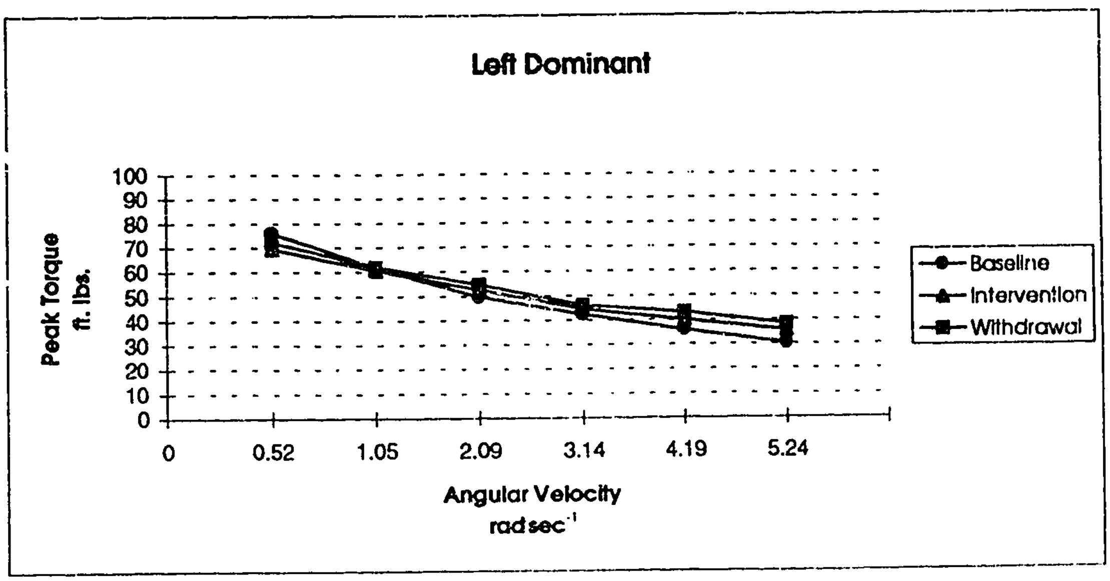
Torque Acceleration Energy vs Angular Velocity
Extension Subject #1



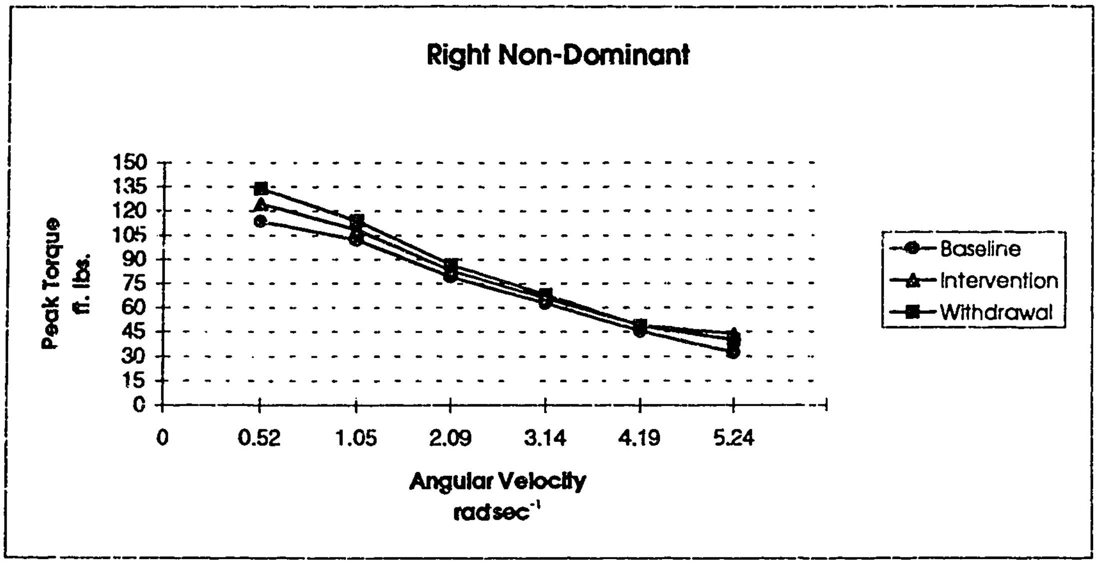


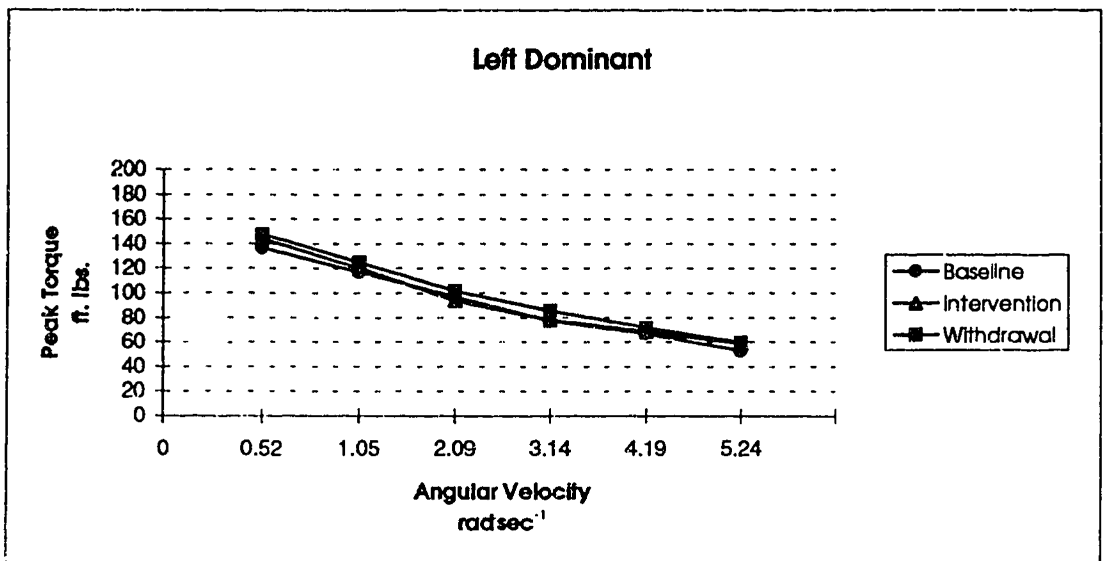
Peak Torque vs Angular Velocity Flexion
Subject #2



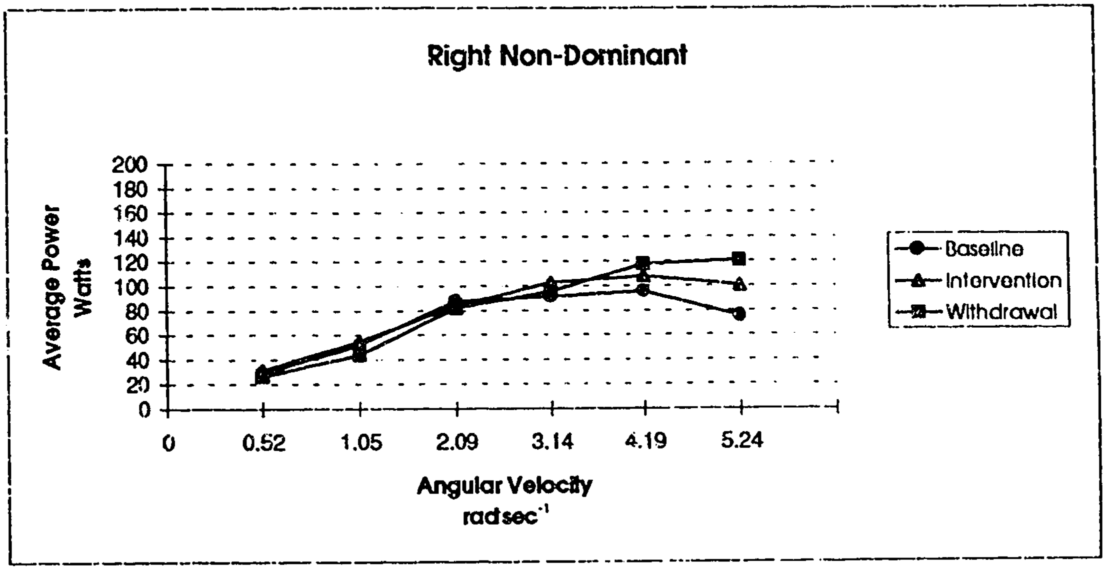


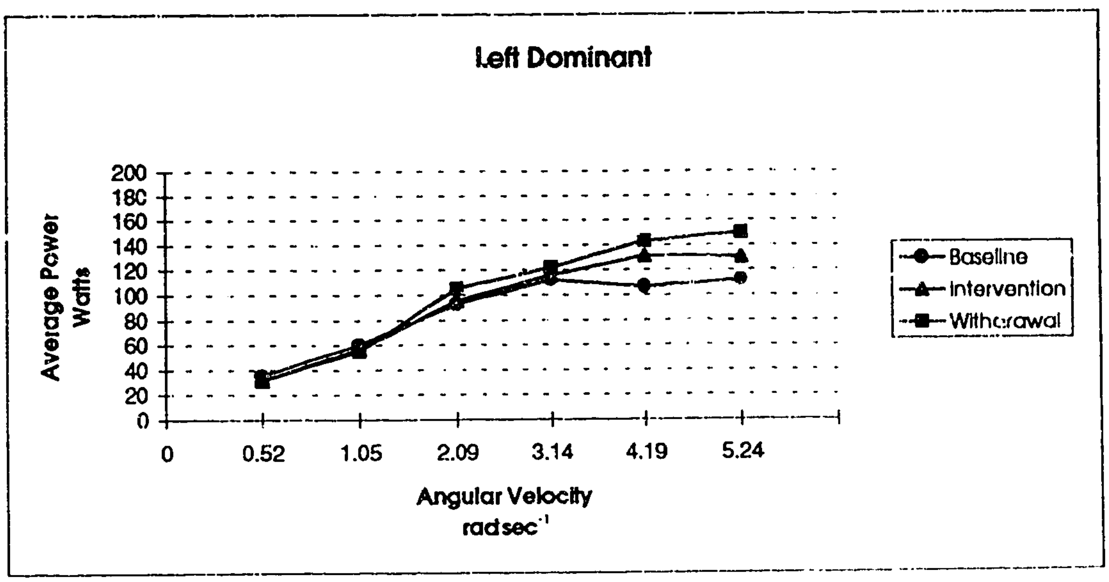
Peak Torque vs Angular Velocity Extension
Subject #2



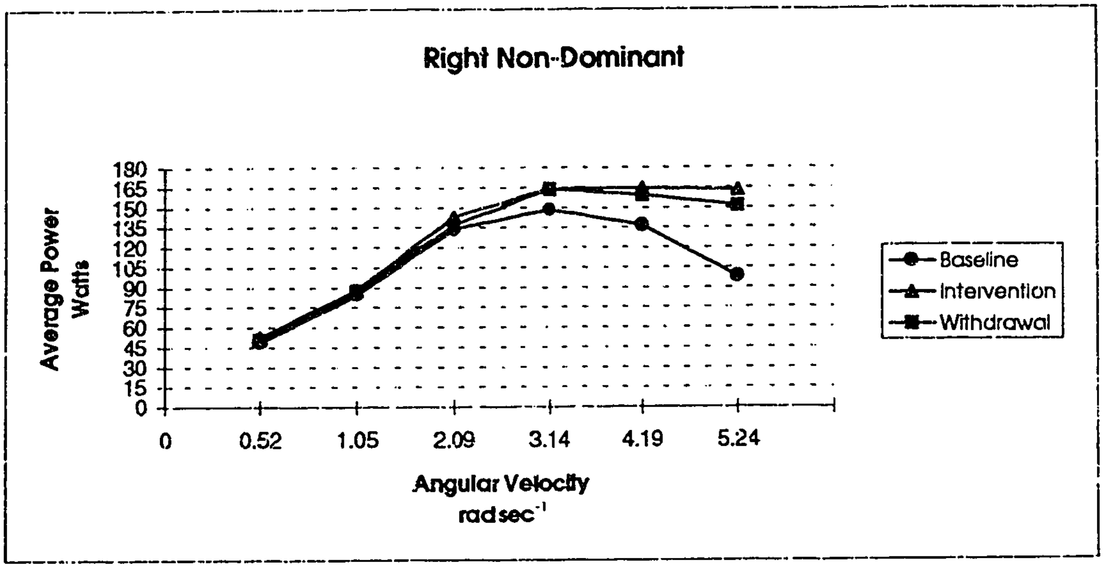


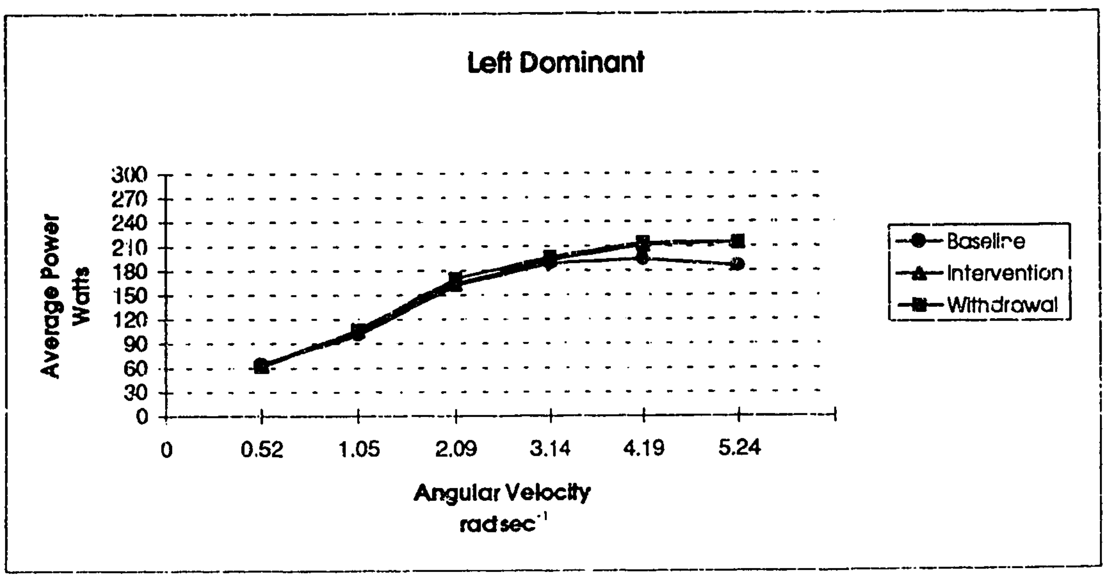
Average Power vs Angular Velocity Flexion
Subject #2



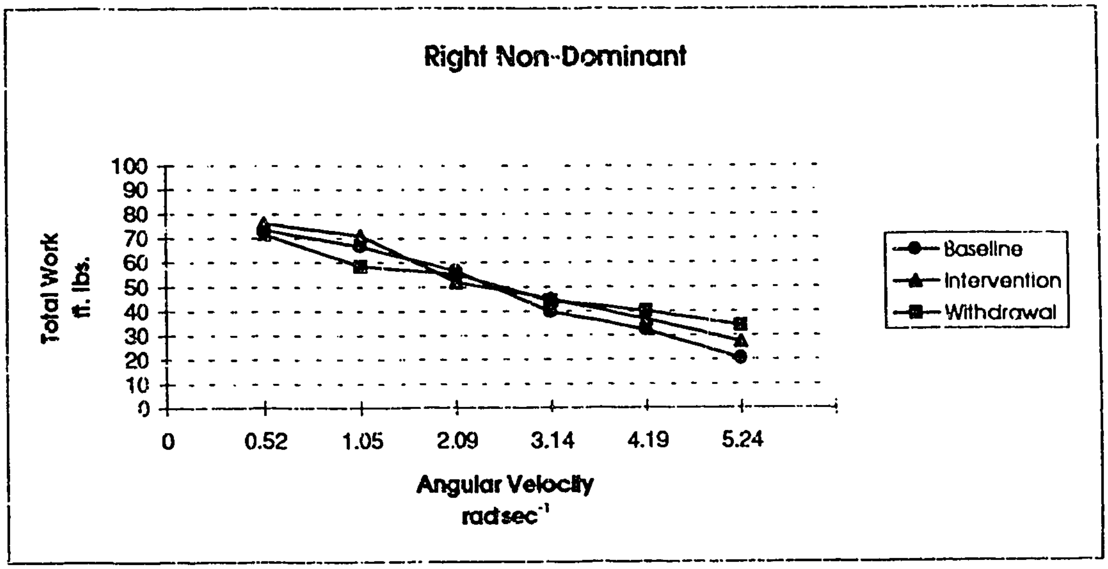


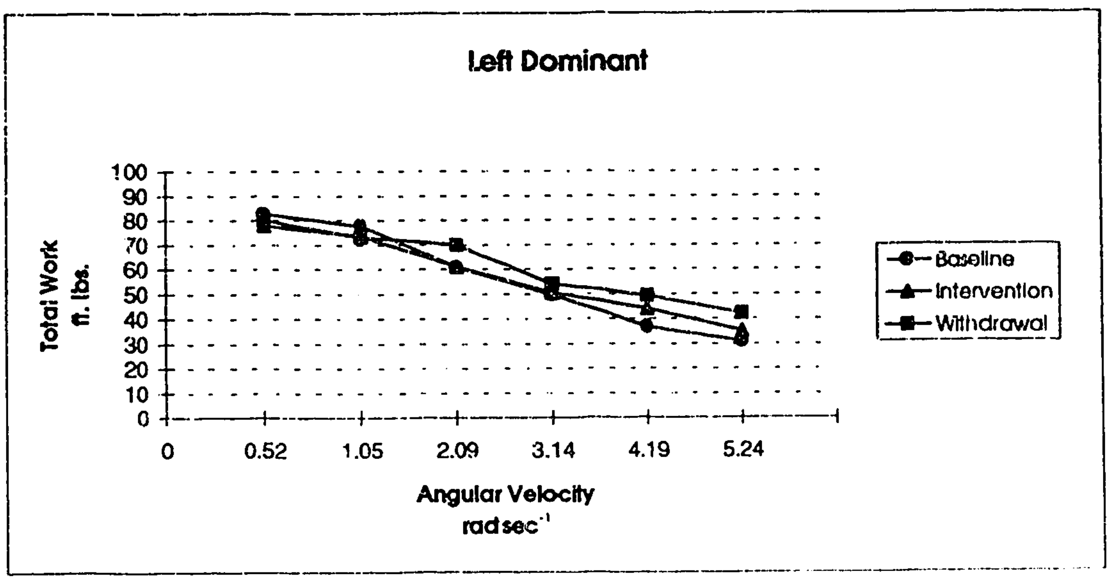
Average Power vs Angular Velocity Extension
Subject #2



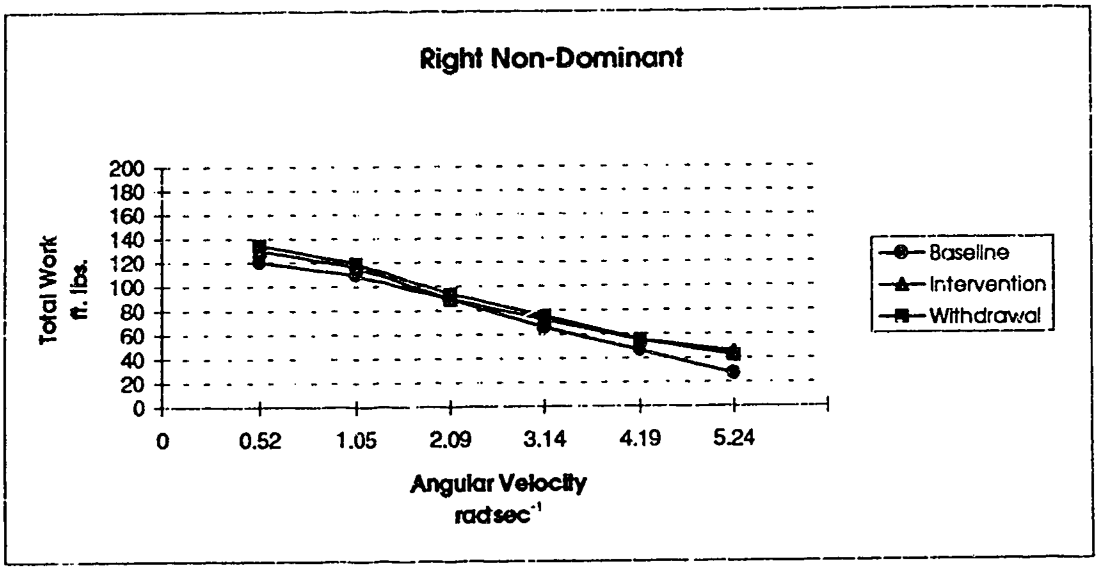


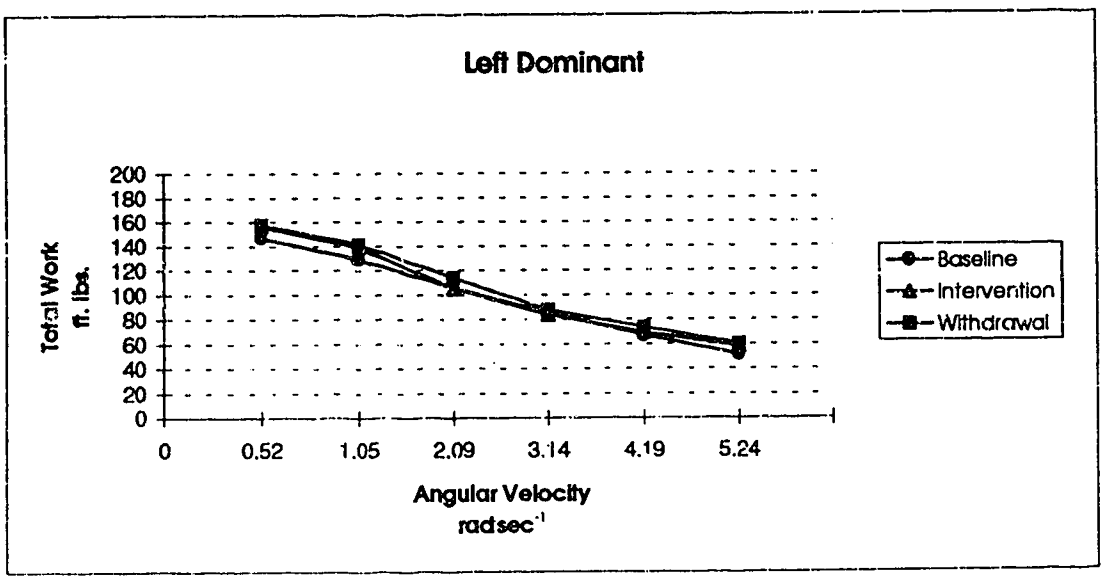
Total Work vs Angular Velocity Flexion
Subject #2



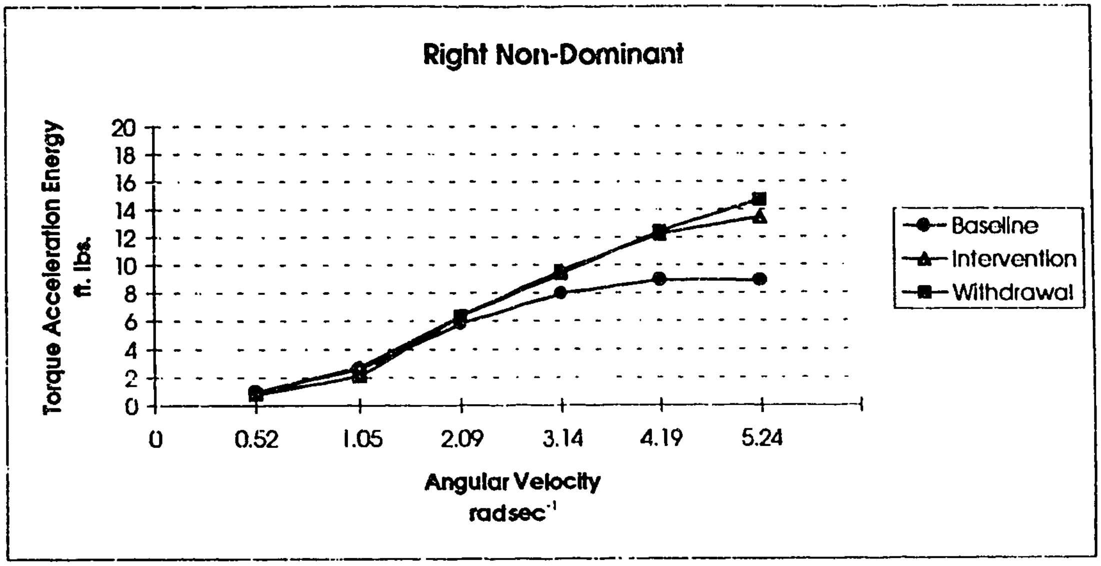


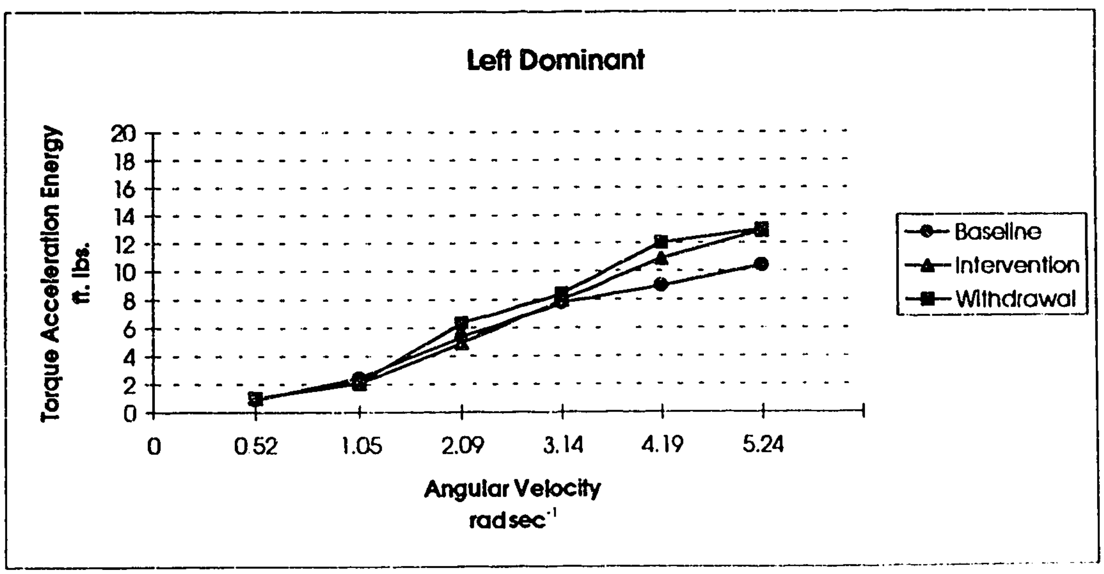
Total Work vs Angular Velocity Extension
Subject #2



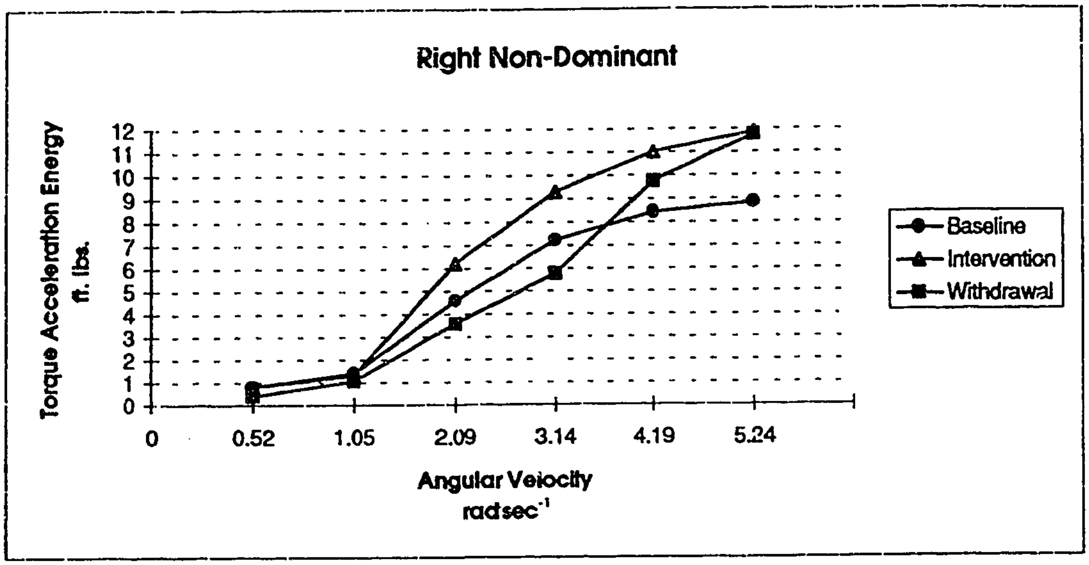


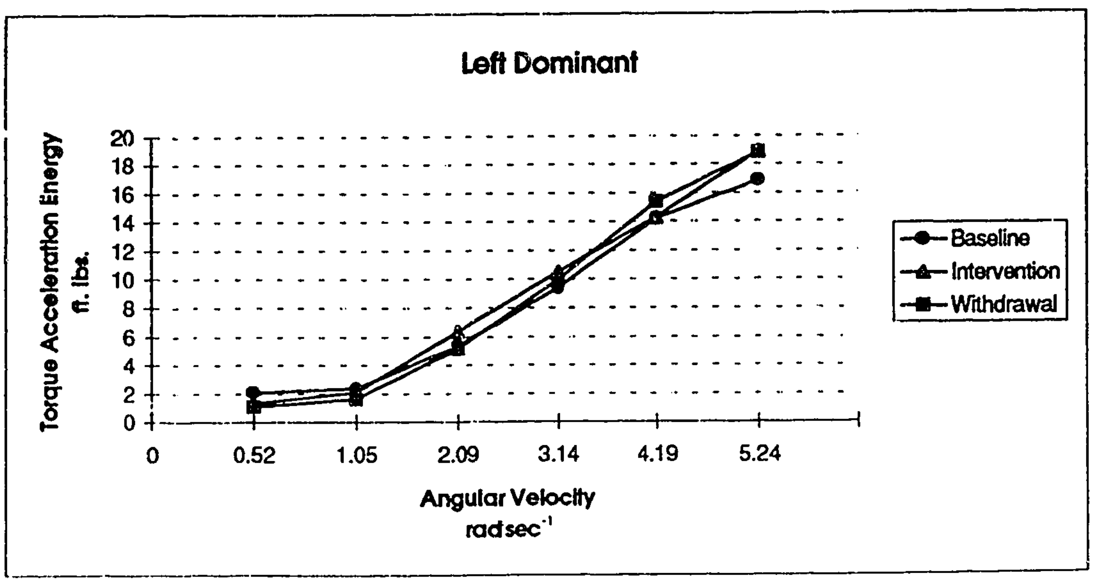
Torque Acceleration Energy vs Angular Velocity Flexion
Subject #2



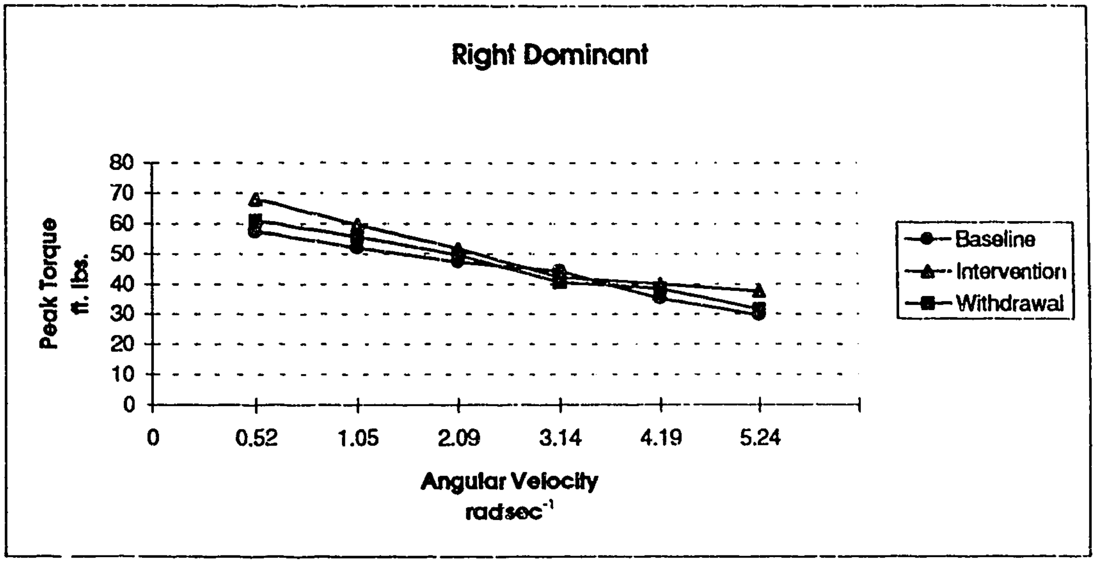


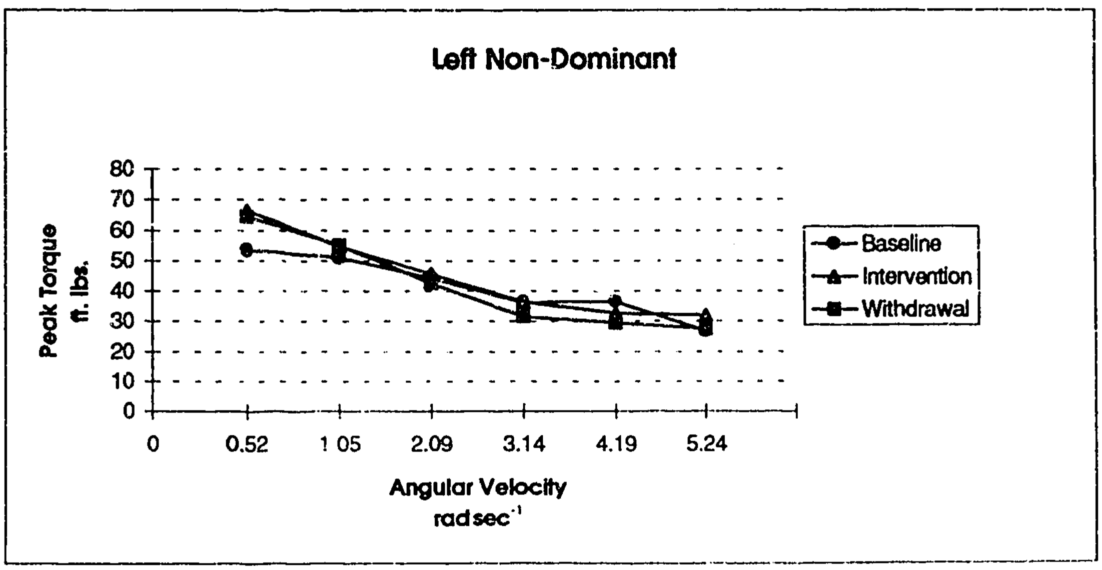
Torque Acceleration Energy vs Angular Velocity
Extension Subject #2



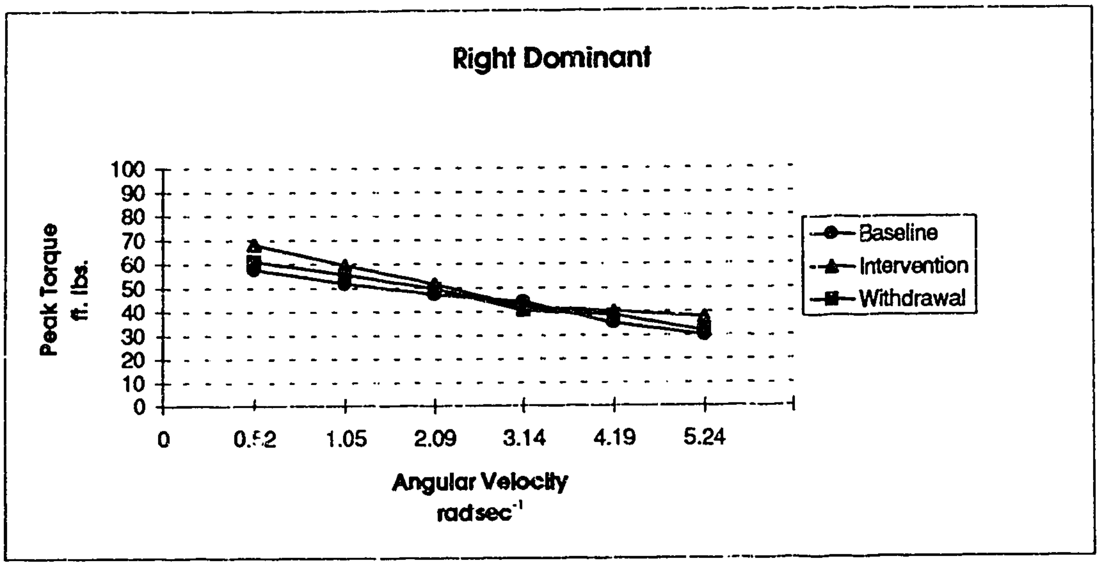


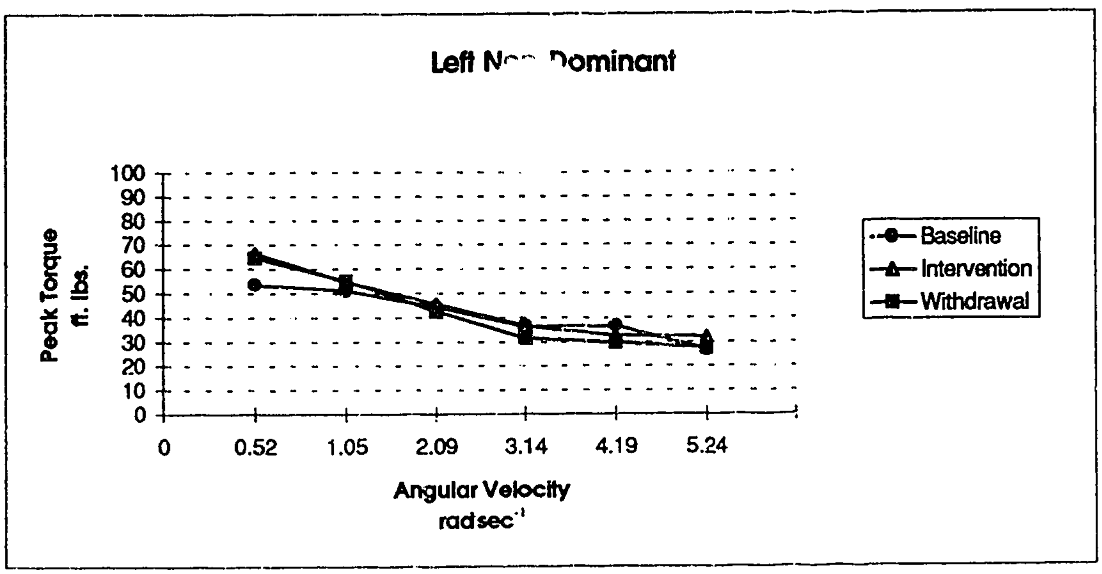
Peak Torque vs Angular Velocity Flexion
Subject #3



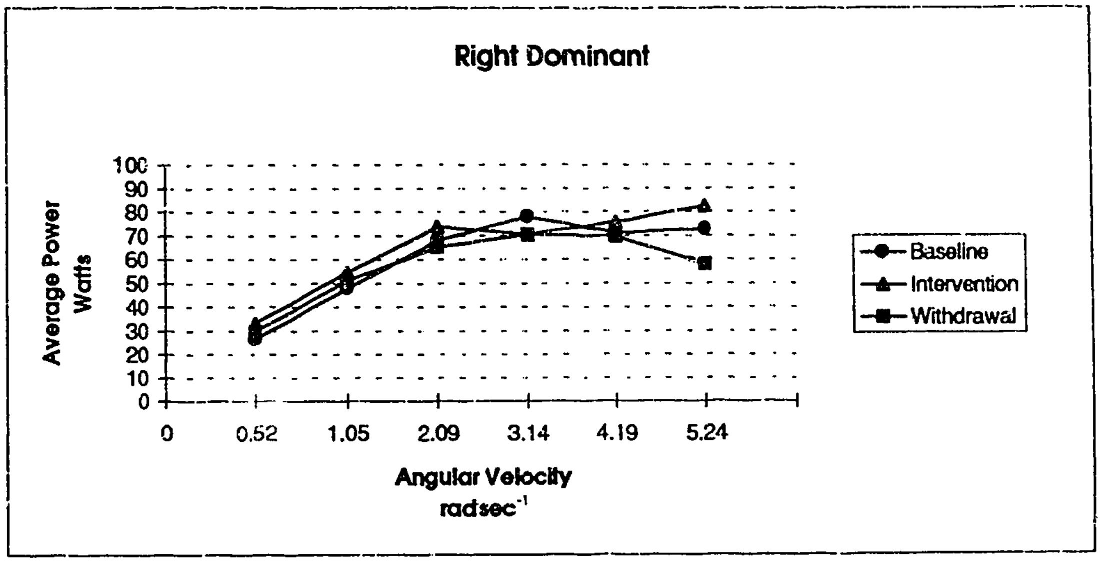


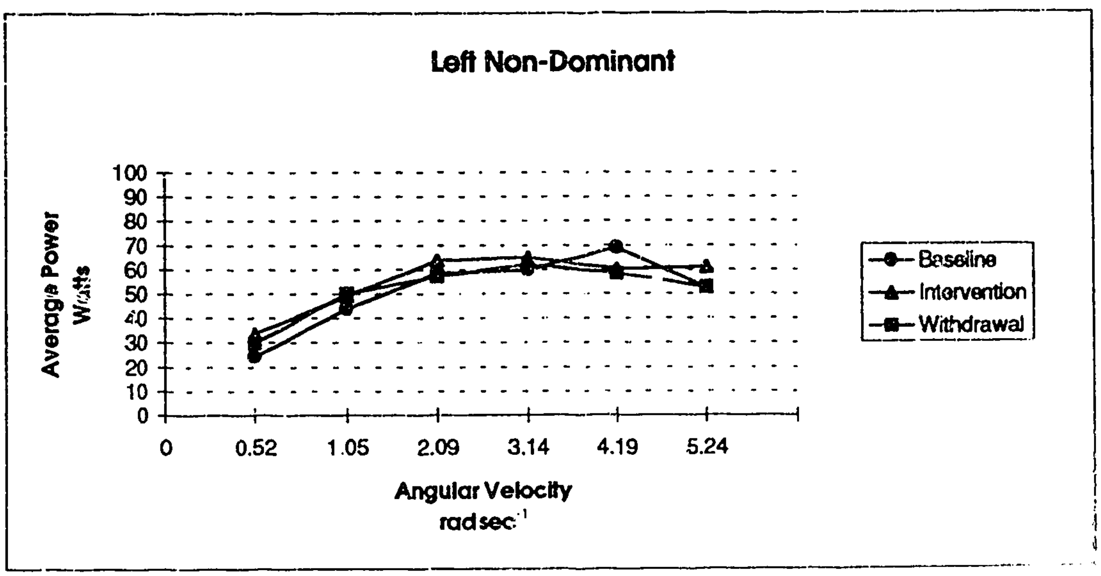
Peak Torque vs Angular Velocity Extension
Subject #3



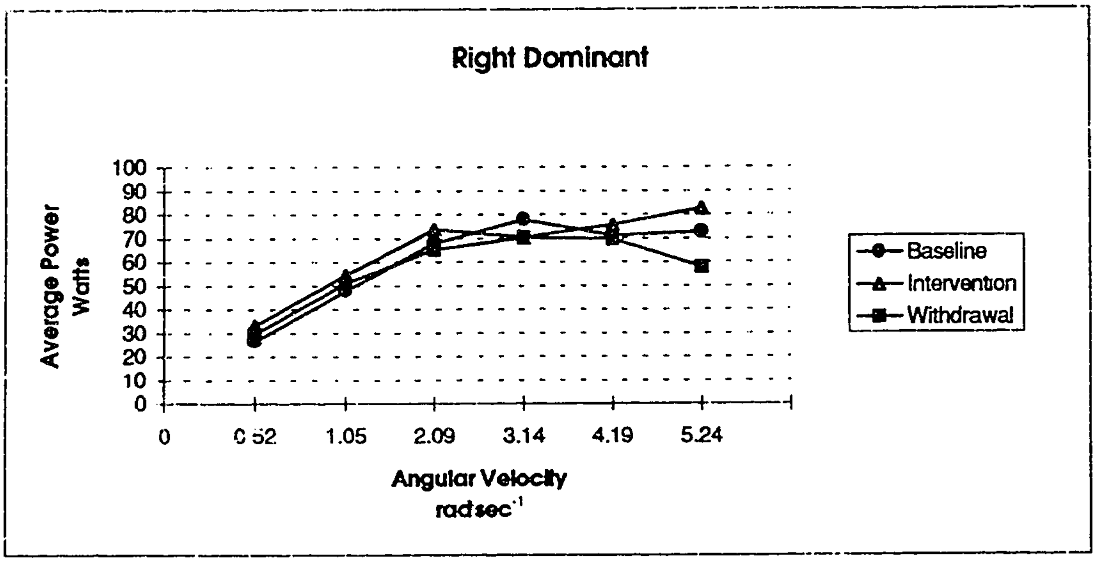


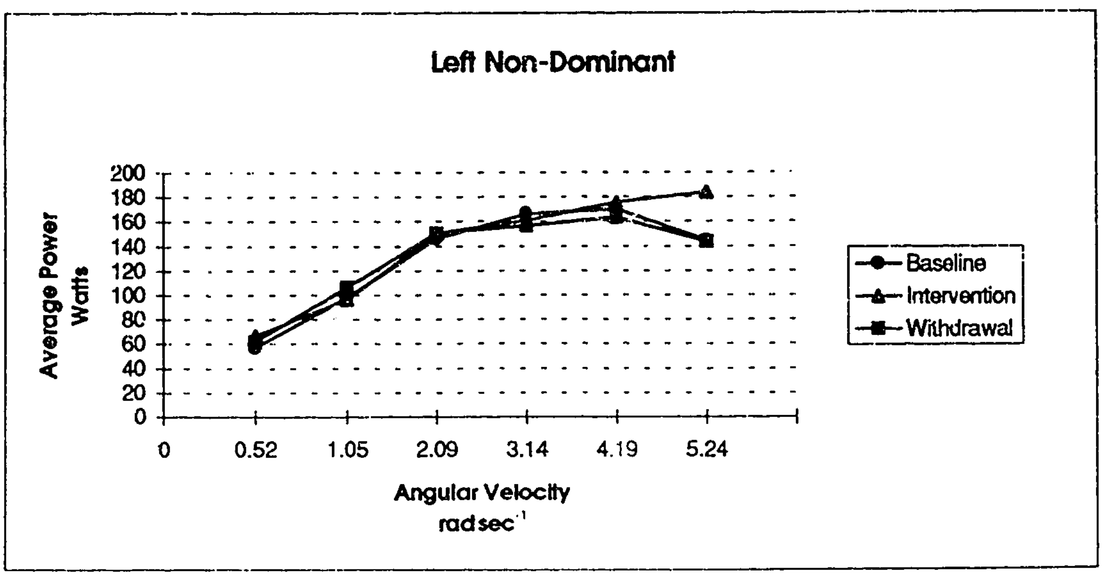
Average Power vs Angular Velocity Flexion
Subject #3



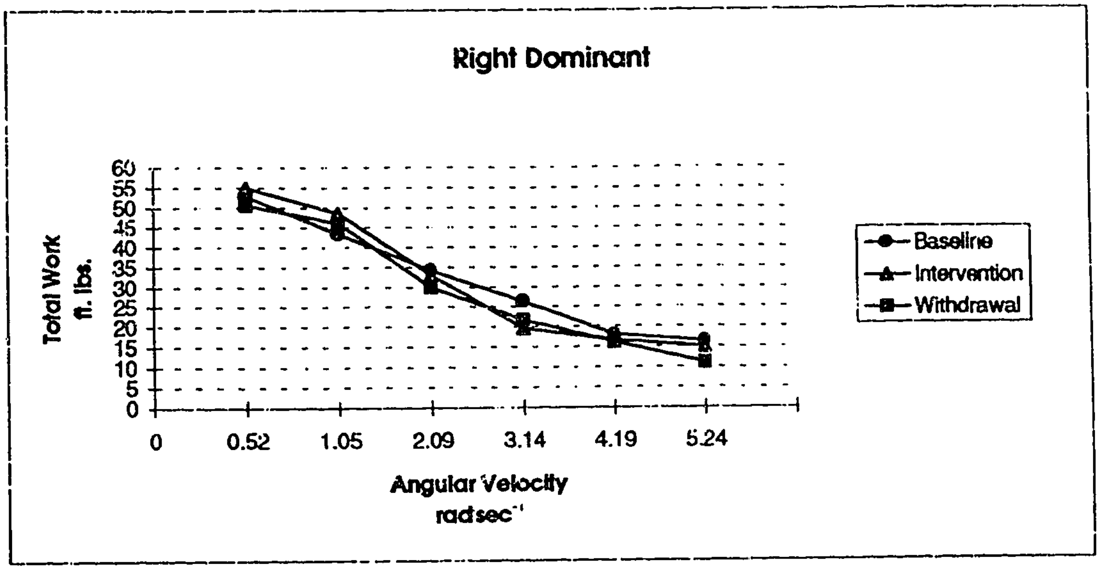


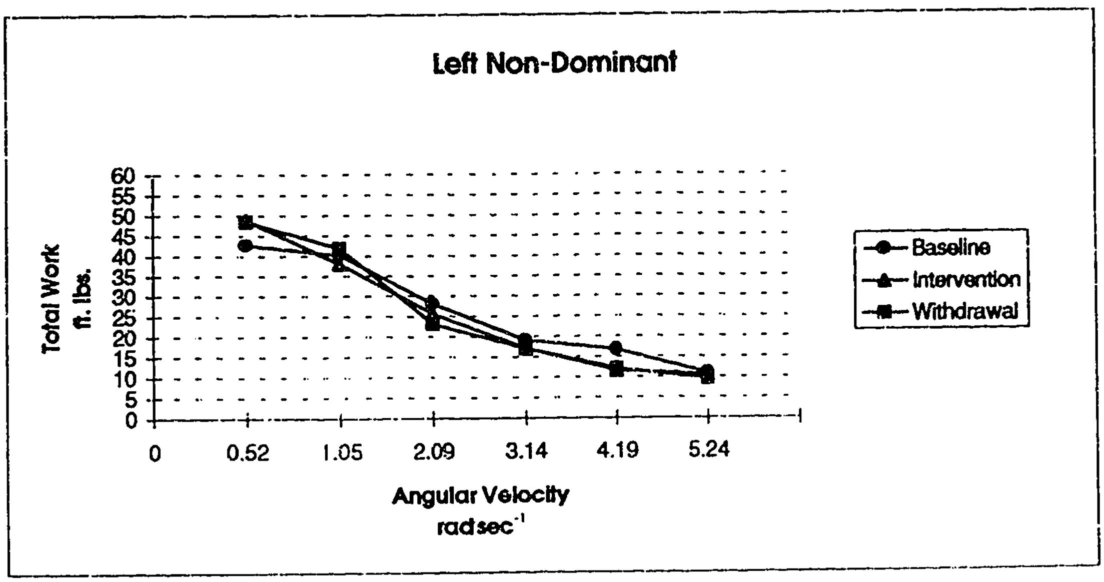
Average Power vs Angular Velocity Extension
Subject #3



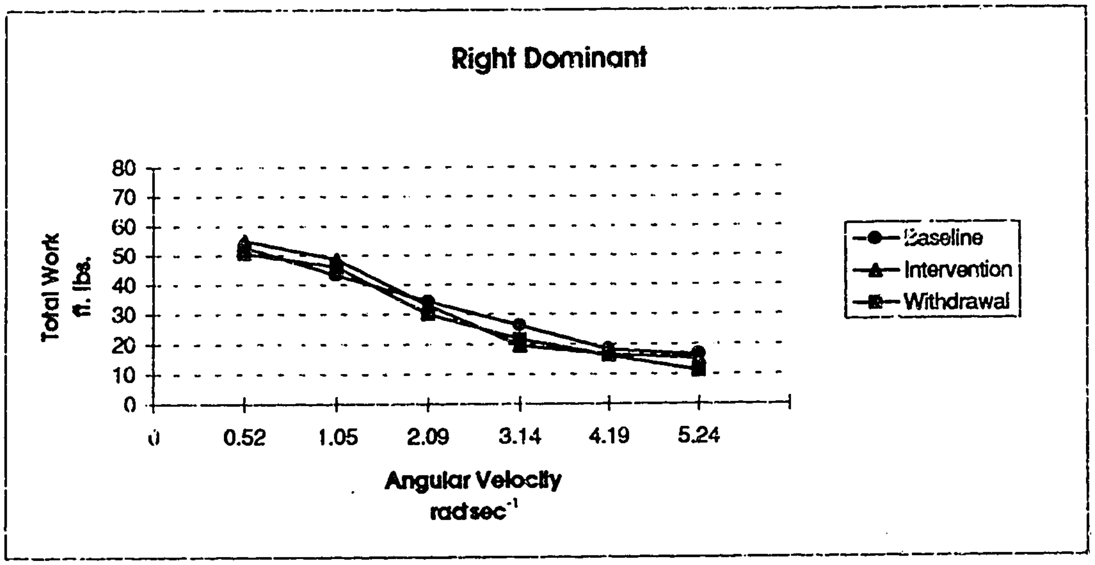


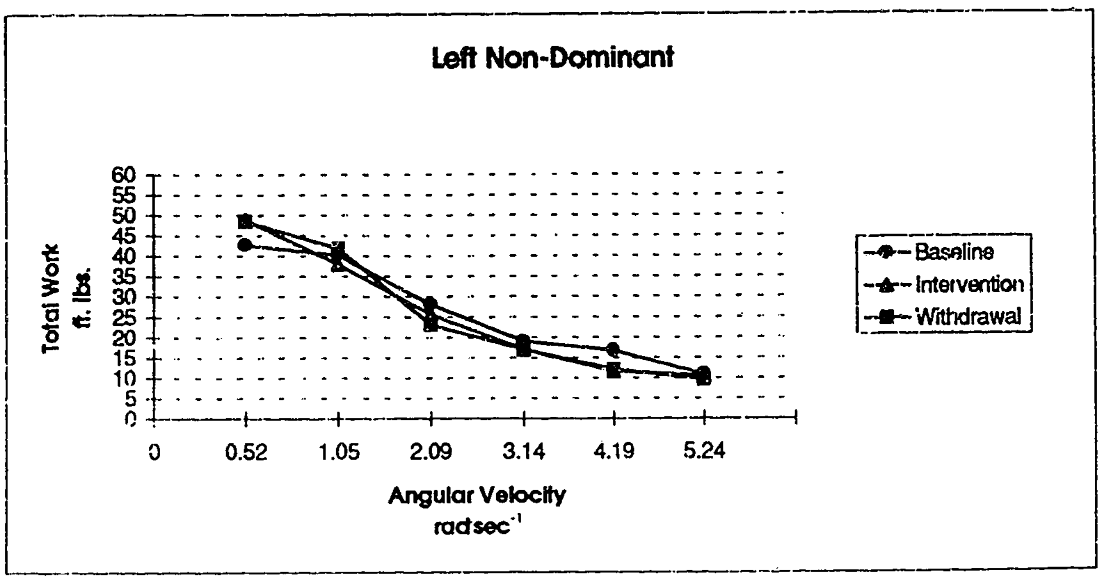
Total Work vs Angular Velocity Flexion
Subject #3



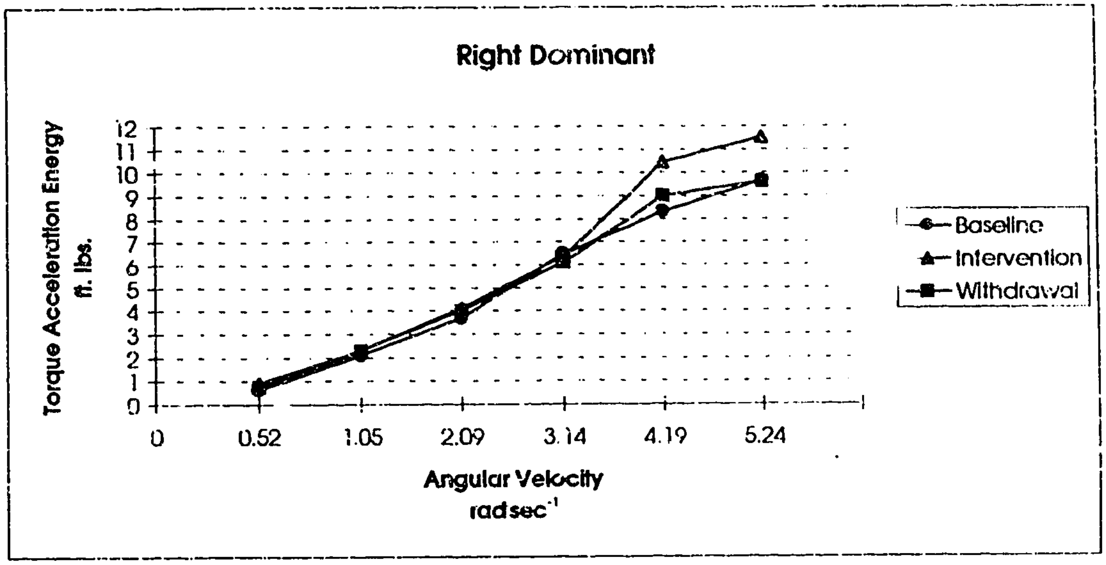


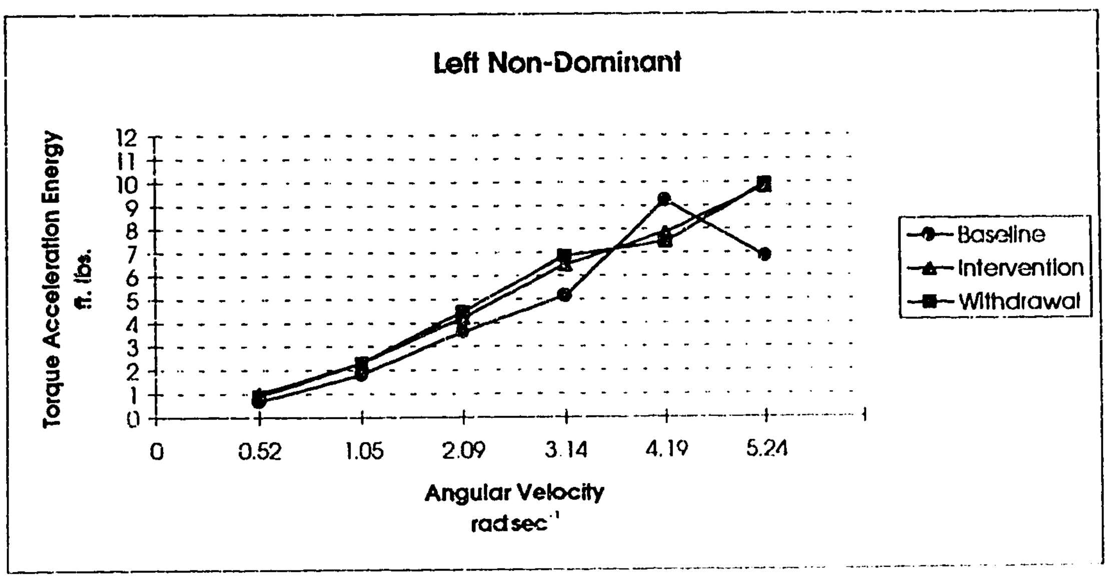
Total Work vs Angular Velocity Extension
Subject #3



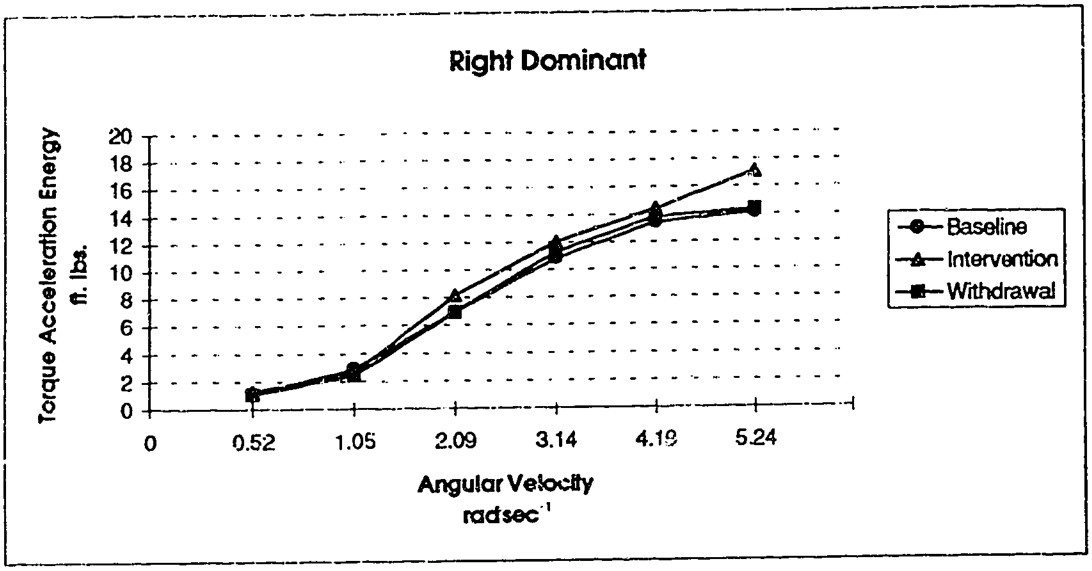


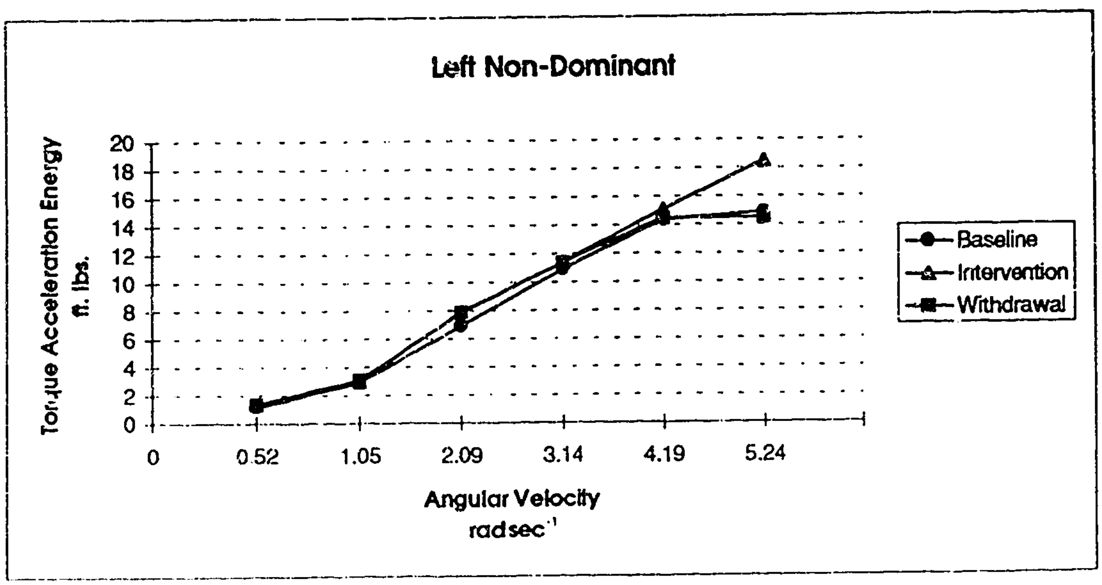
Torque Acceleration Energy vs Angular Velocity Flexion
Subject #3



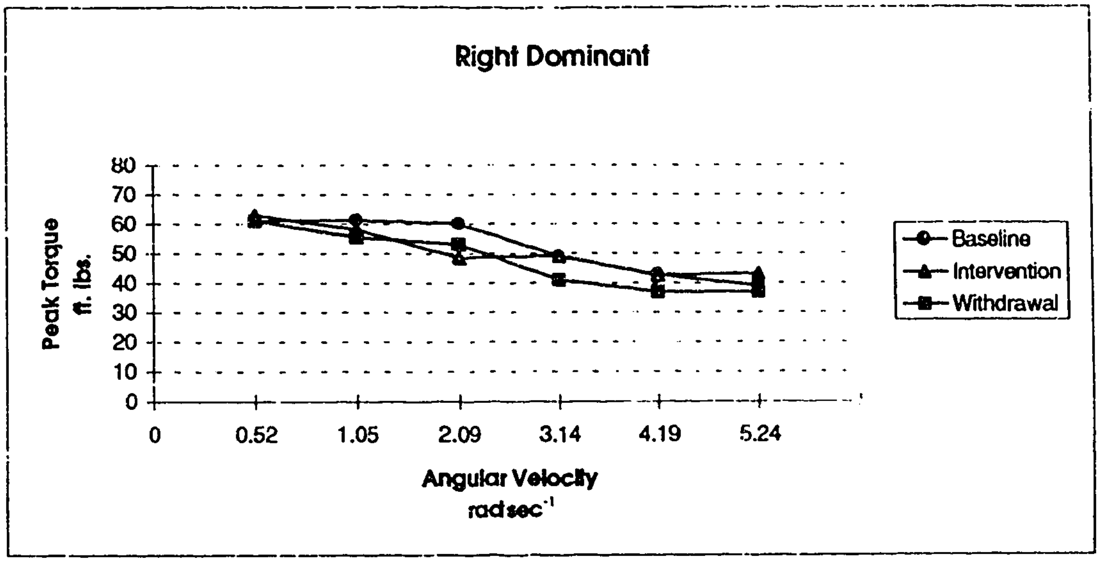


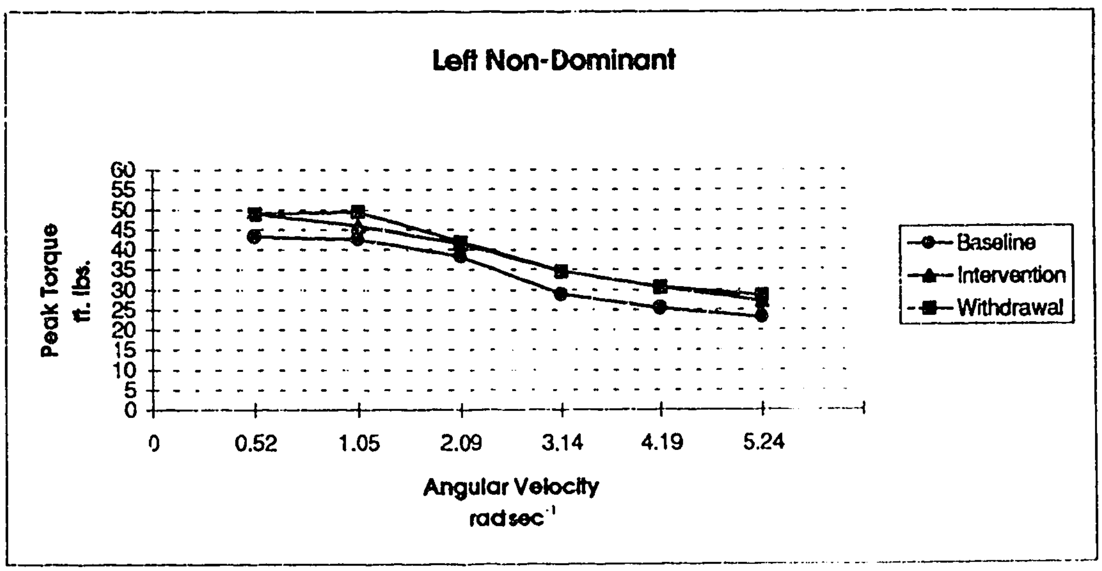
Torque Acceleration Energy vs Angular Velocity
Extension Subject #3



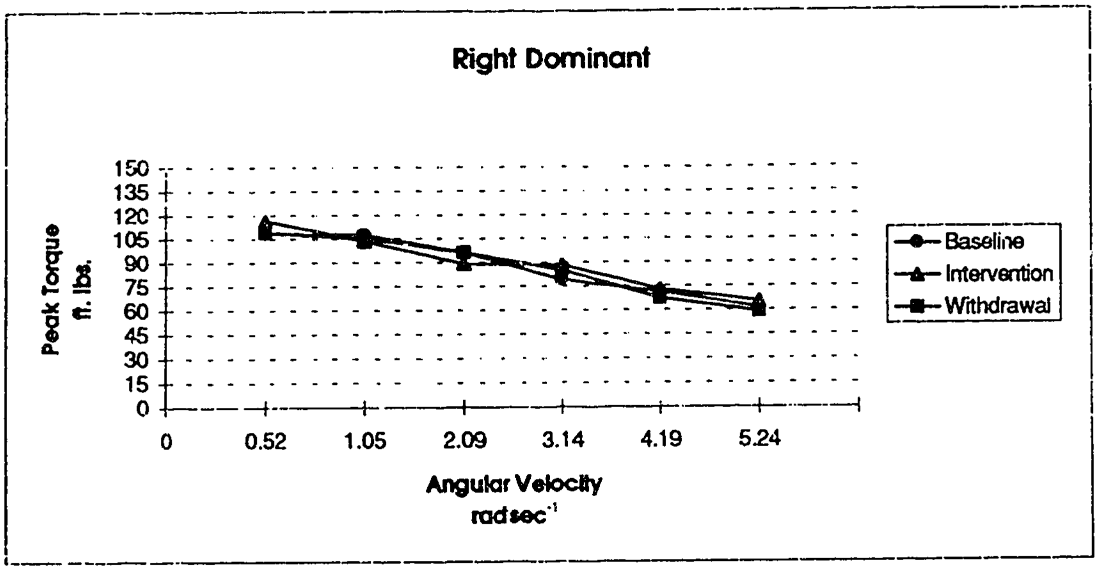


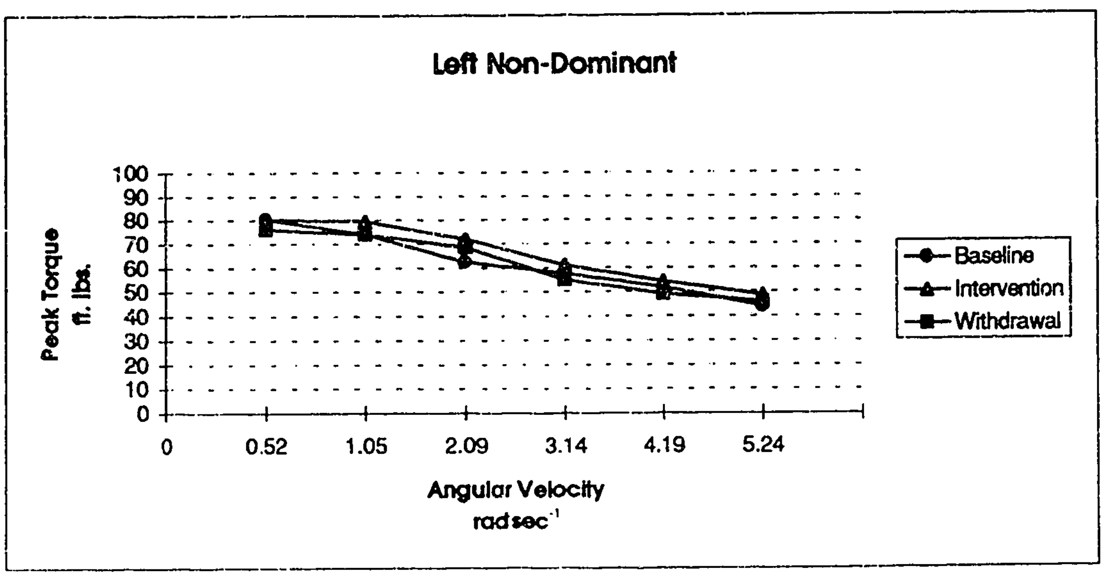
Peak Torque vs Angular Velocity Flexion Subject #4



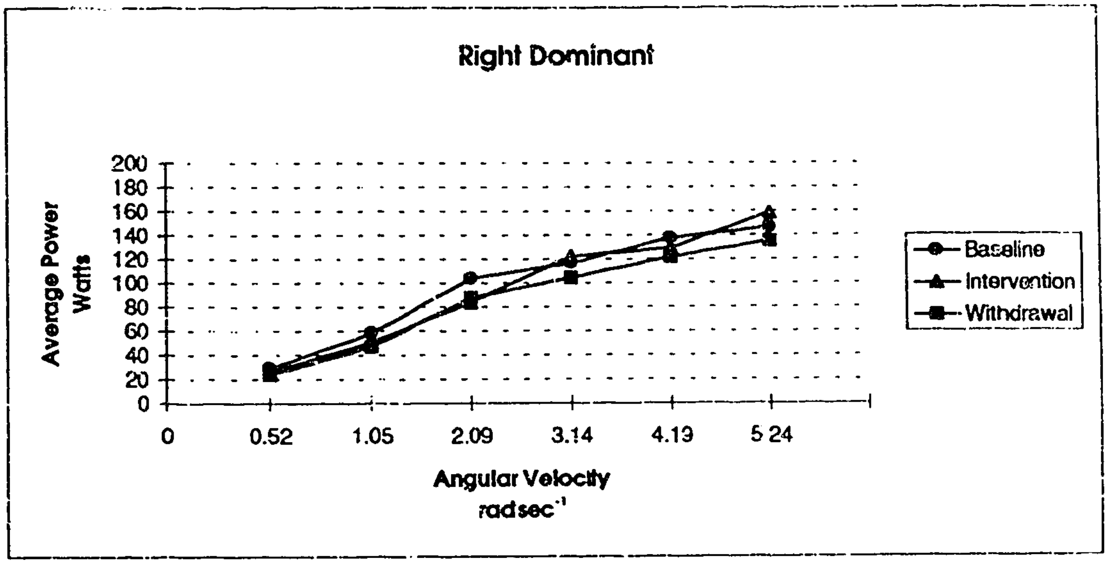


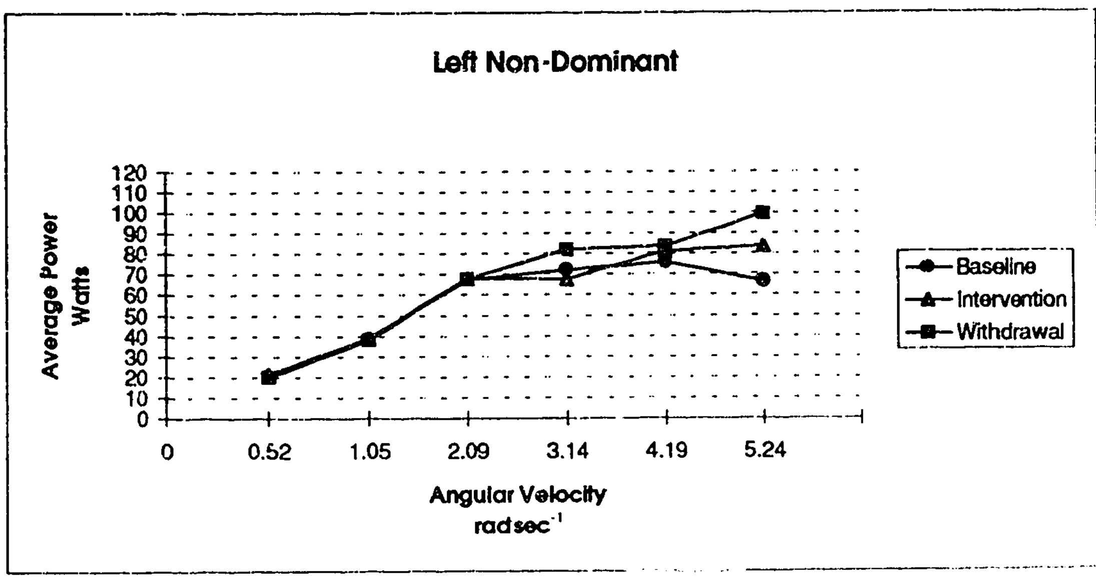
Peak Torque vs Angular Velocity Extension
Subject #4



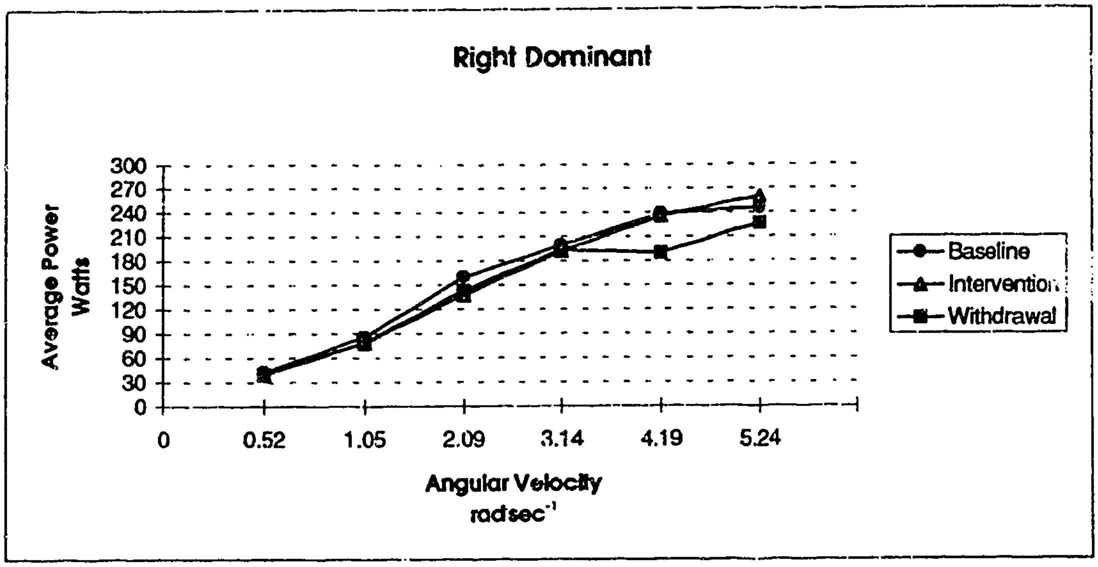


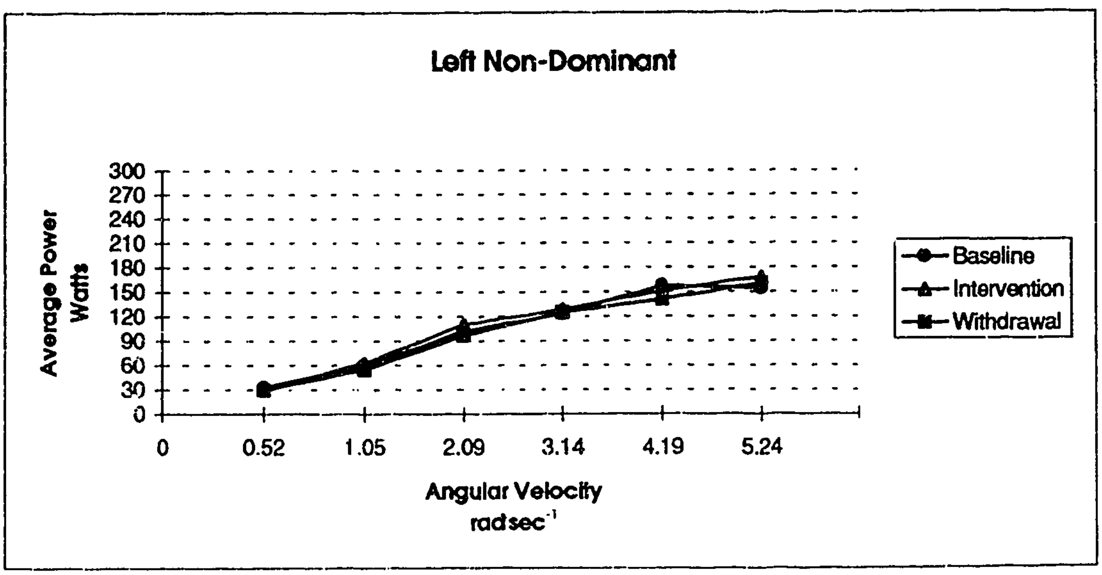
Average Power vs Angular Velocity Flexion
Subject #4



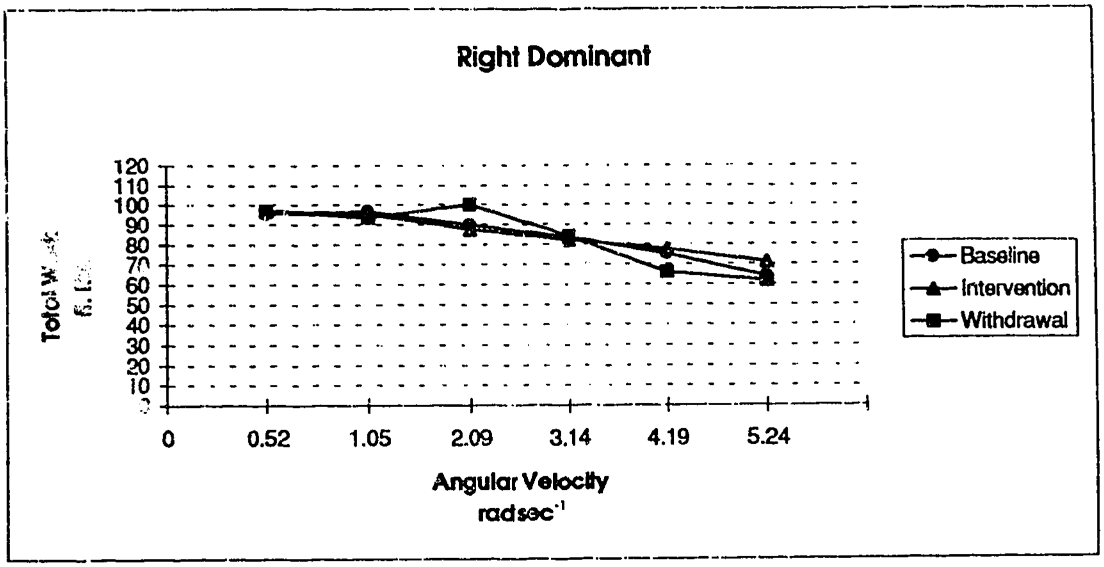


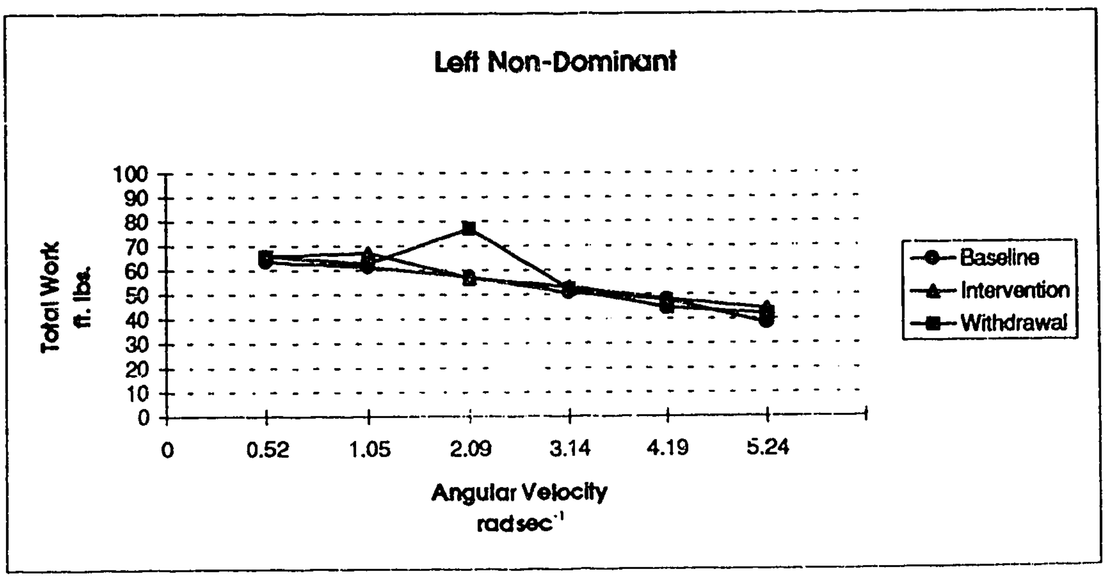
Average Power vs Angular Velocity Extension
Subject #4



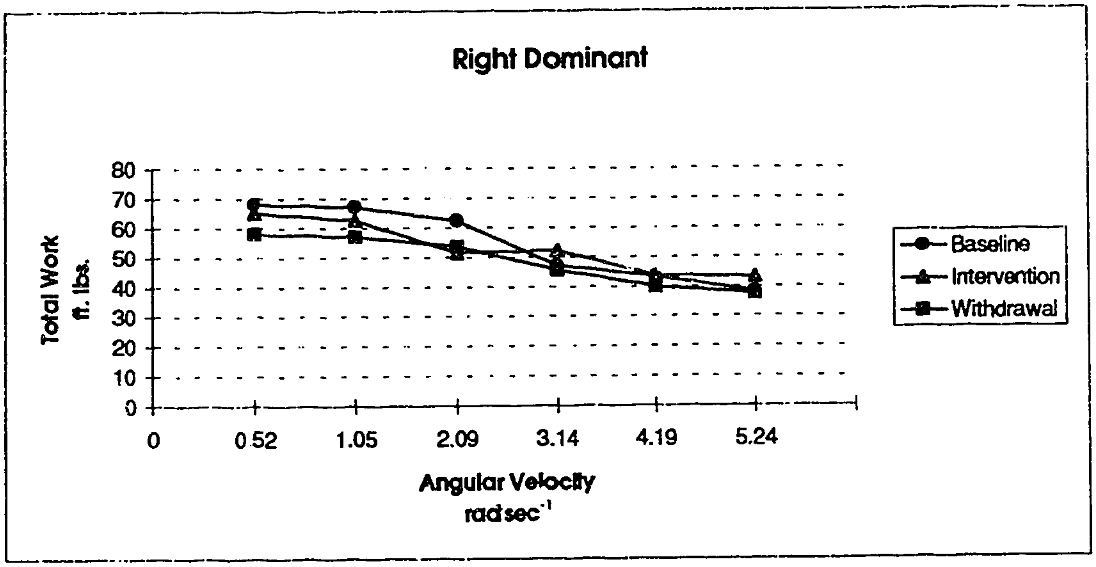


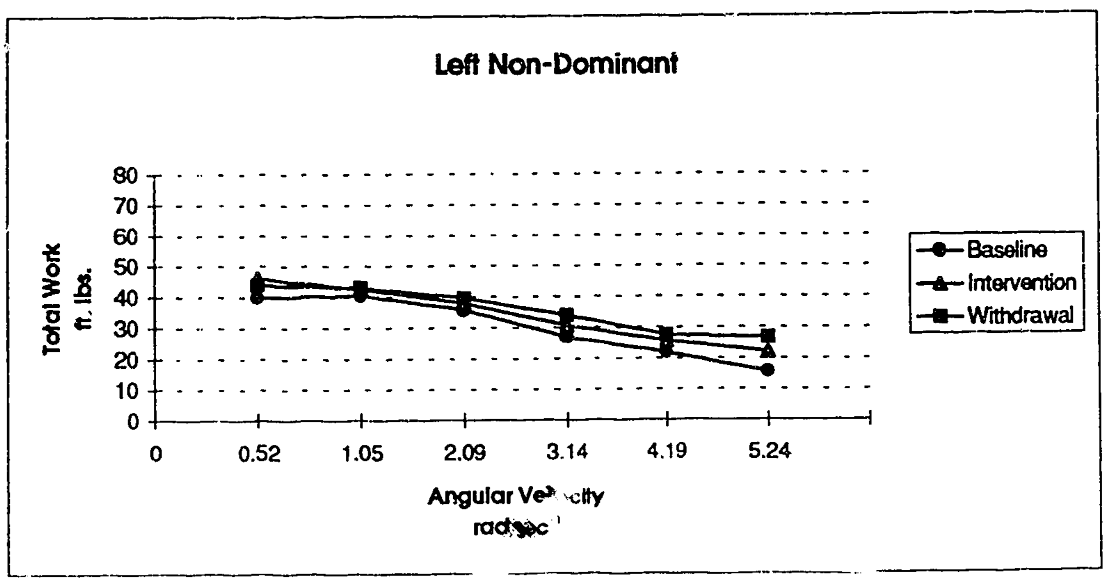
Total Work vs Angular Velocity Extension
Subject #4



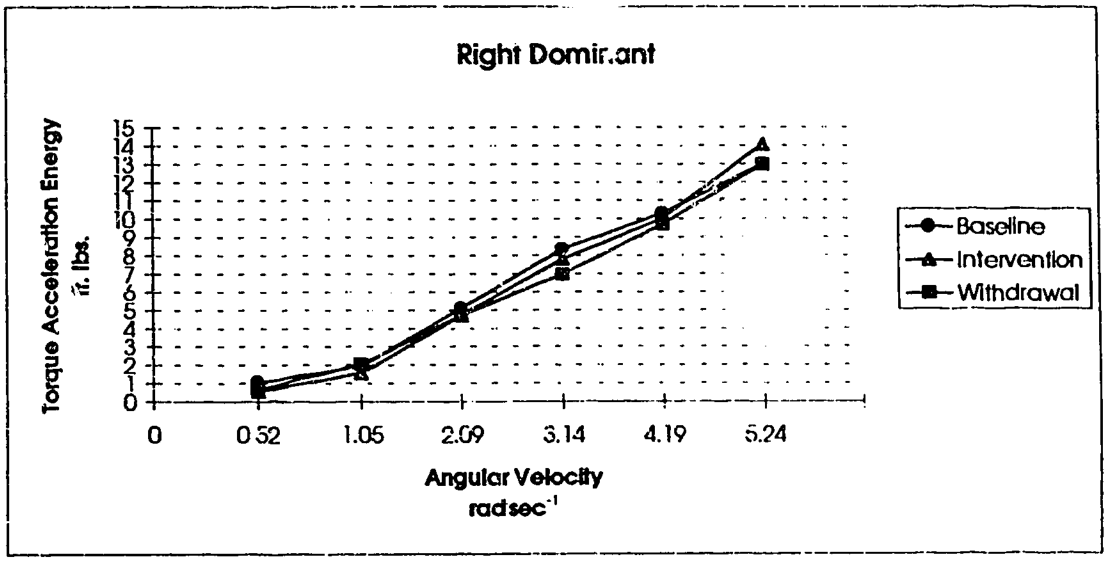


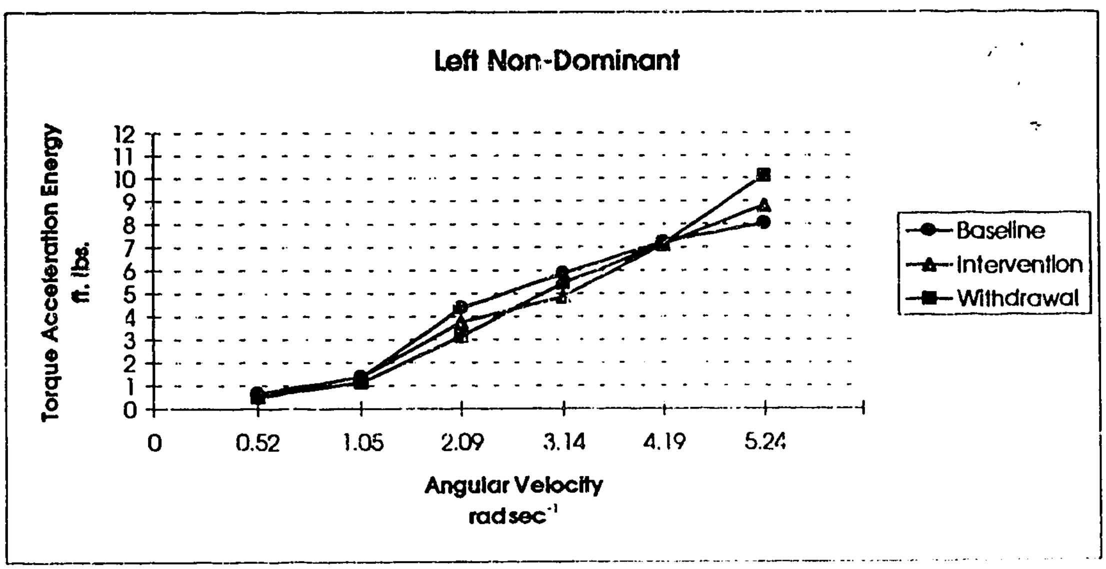
Total Work vs Angular Velocity Flexion
Subject #4



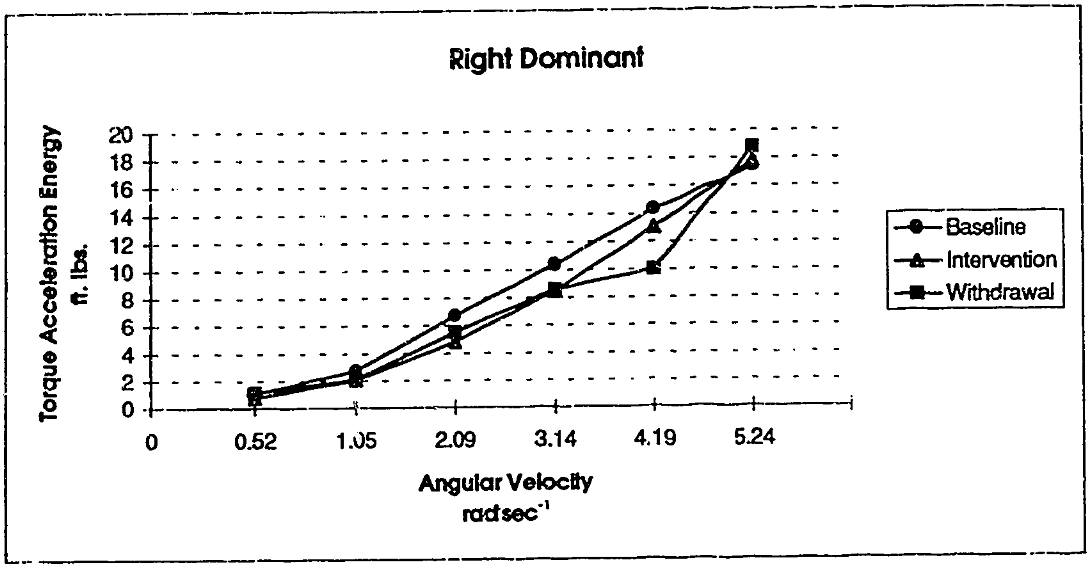


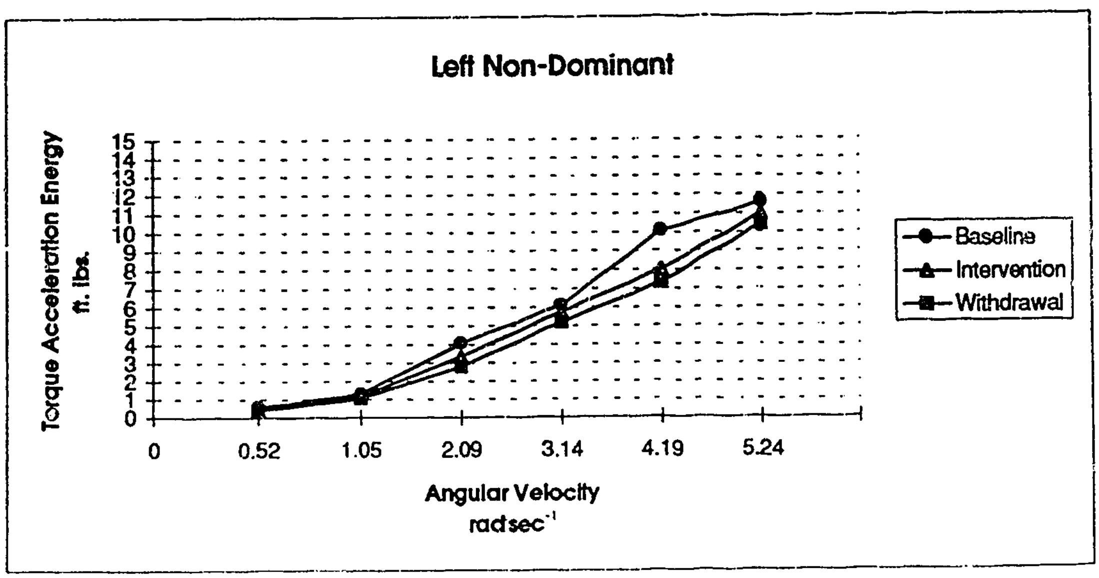
Torque Acceleration Energy vs Angular Velocity Flexion
Subject #4



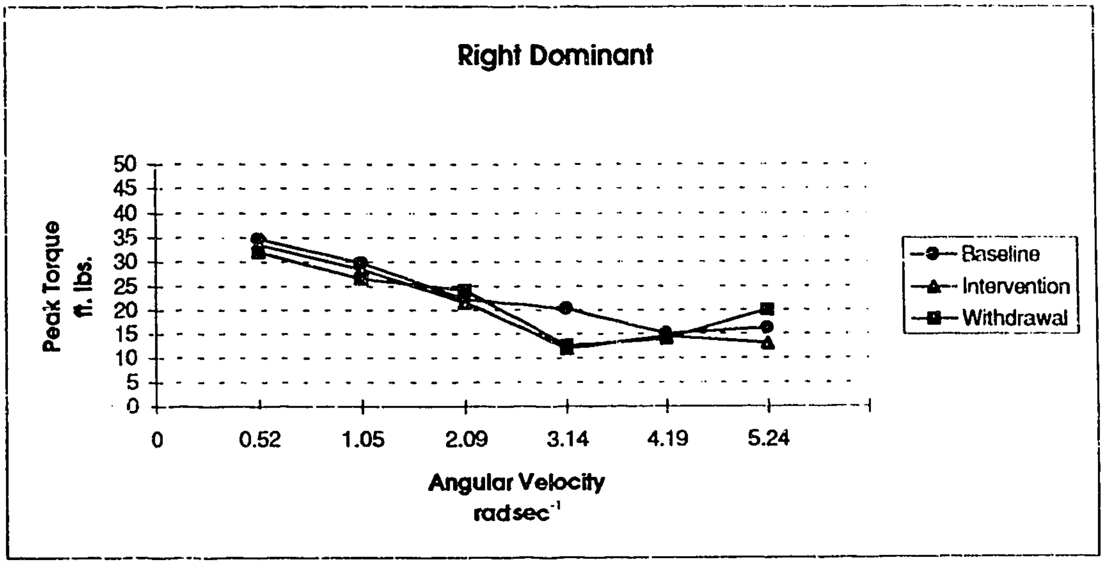


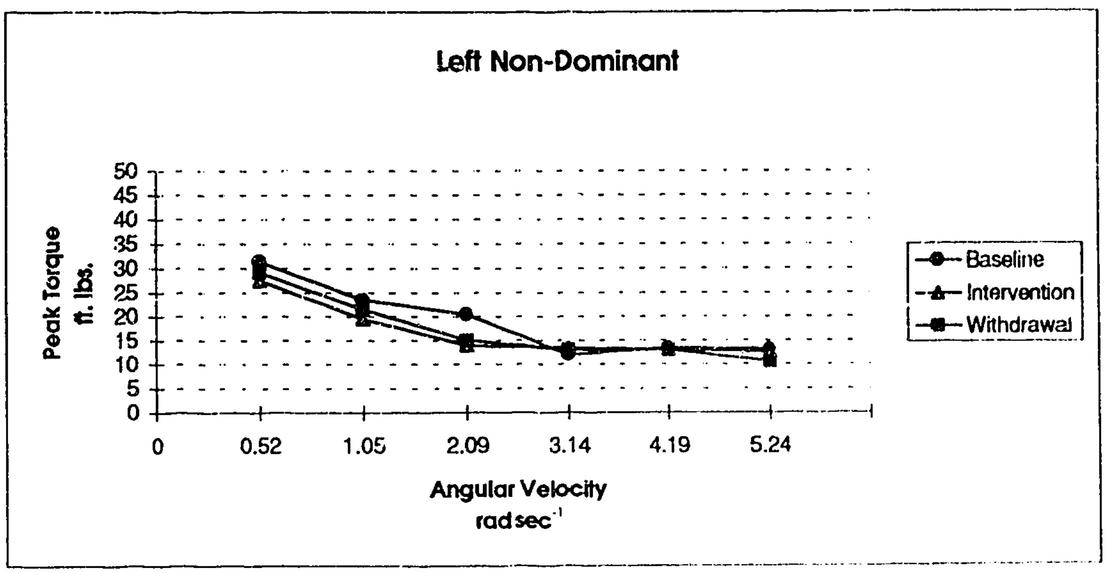
Torque Acceleration Energy vs Angular Velocity
Extension Subject #4



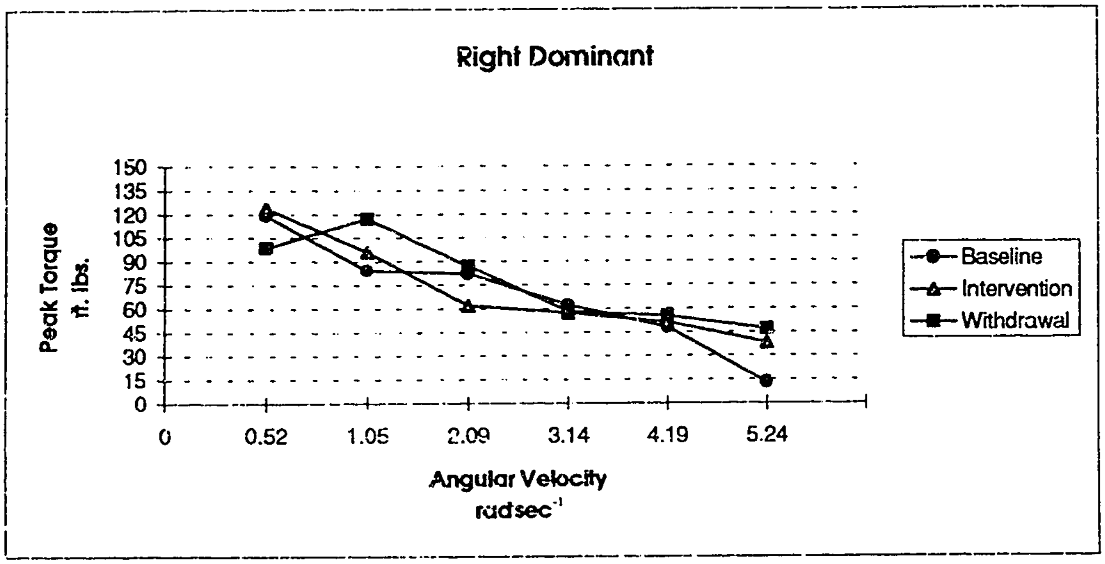


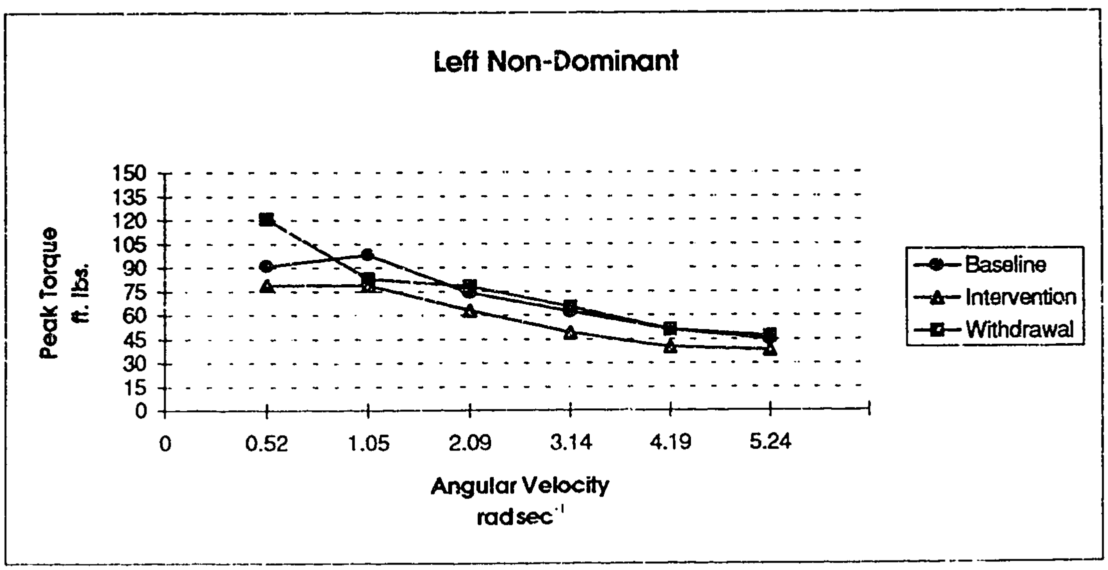
Peak Torque vs Angular Velocity Flexion
Subject #5



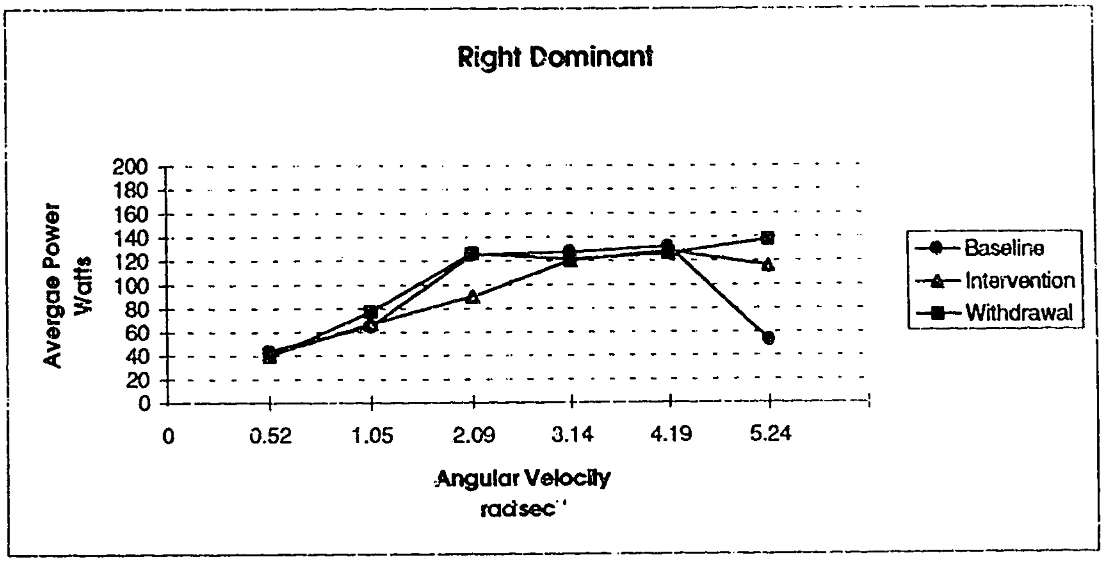


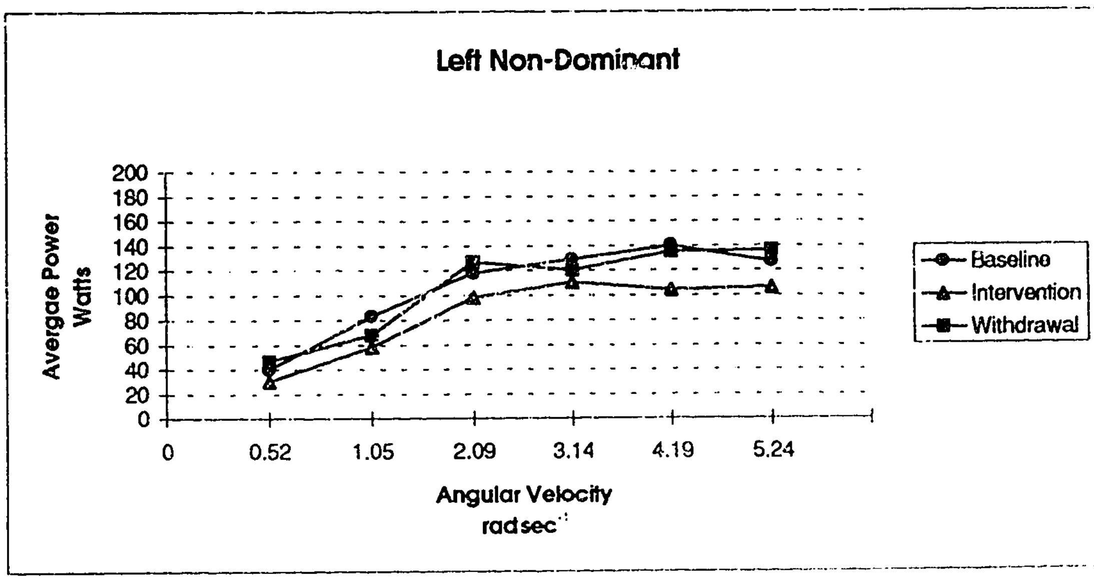
Peak Torque vs Angular Velocity Extension
Subject #5



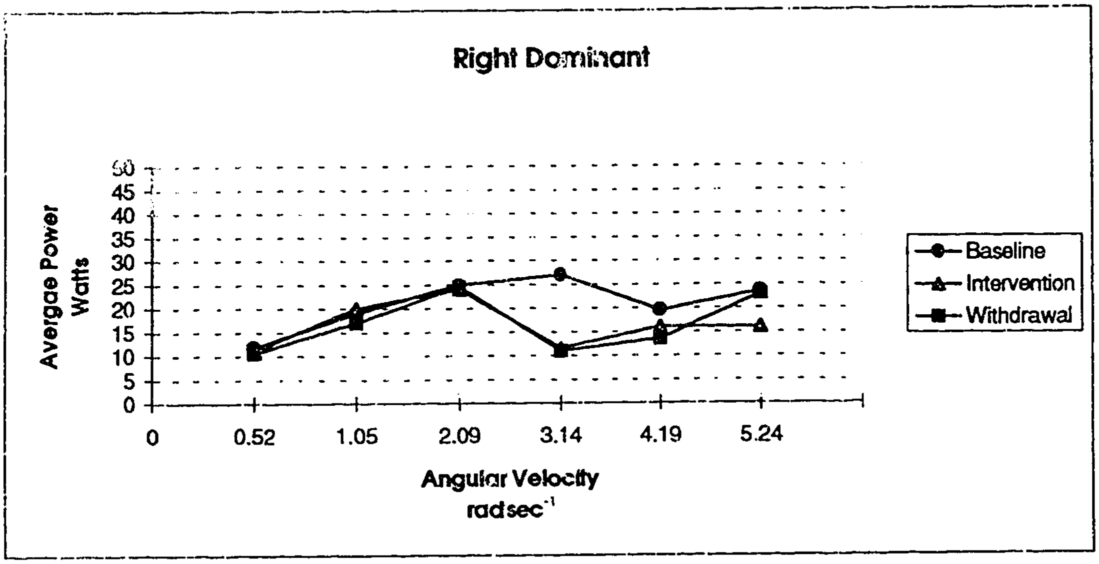


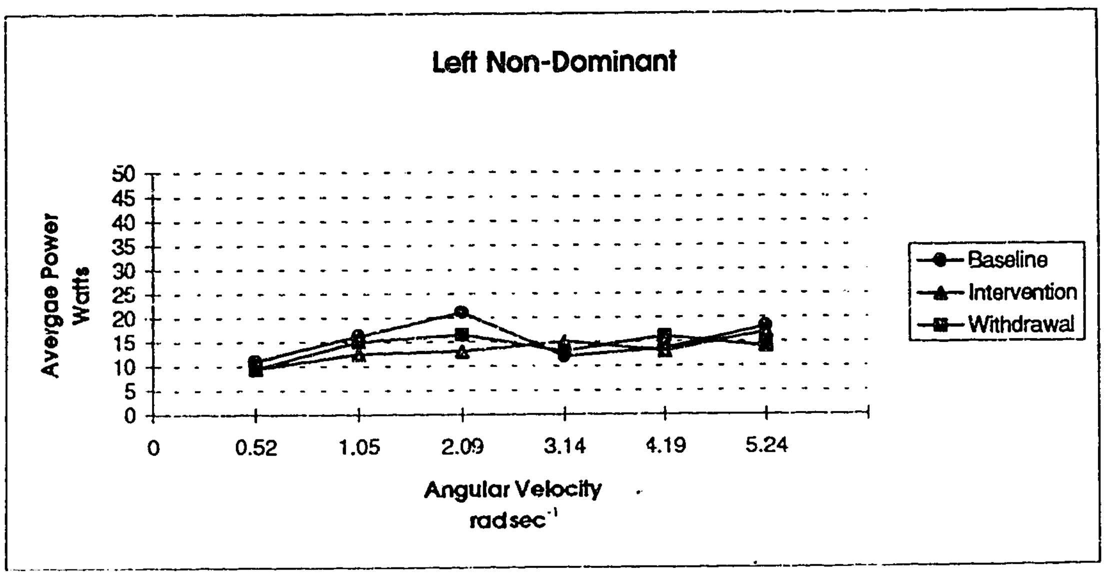
Average Power vs Angular Velocity Extension
Subject #5



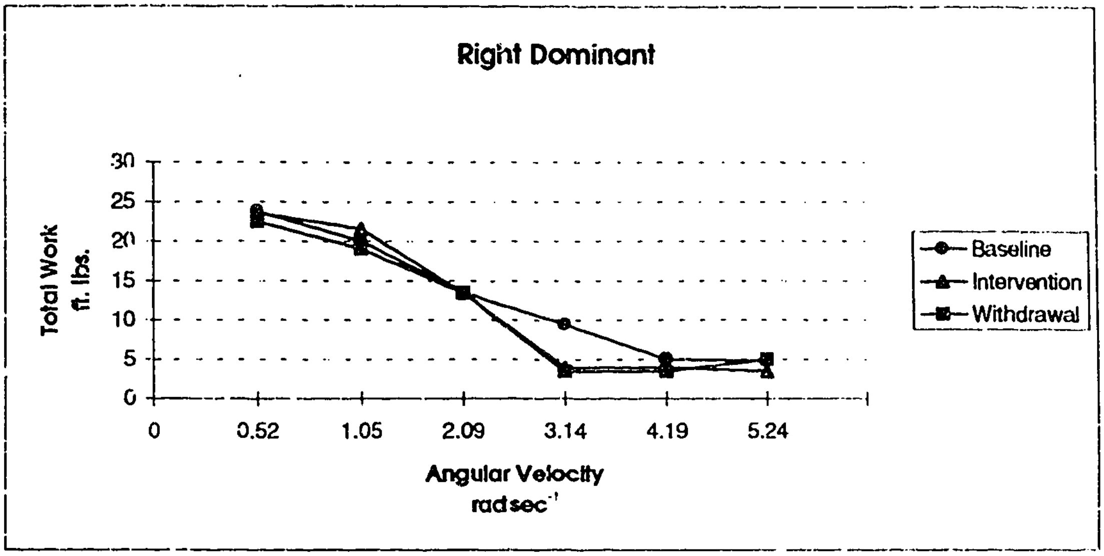


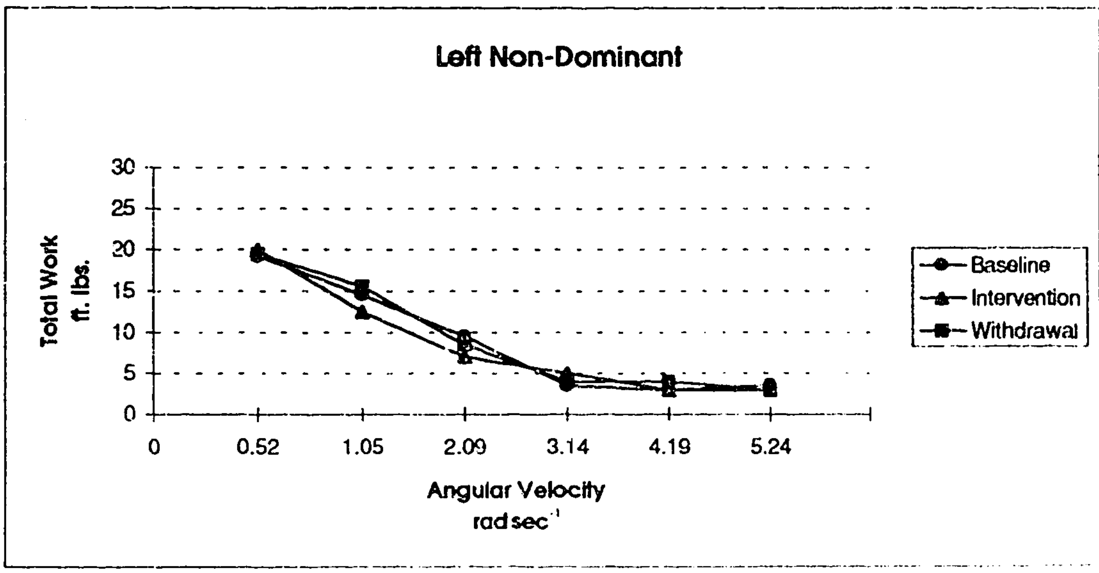
Average Power vs Angular Velocity Flexion
Subject #5



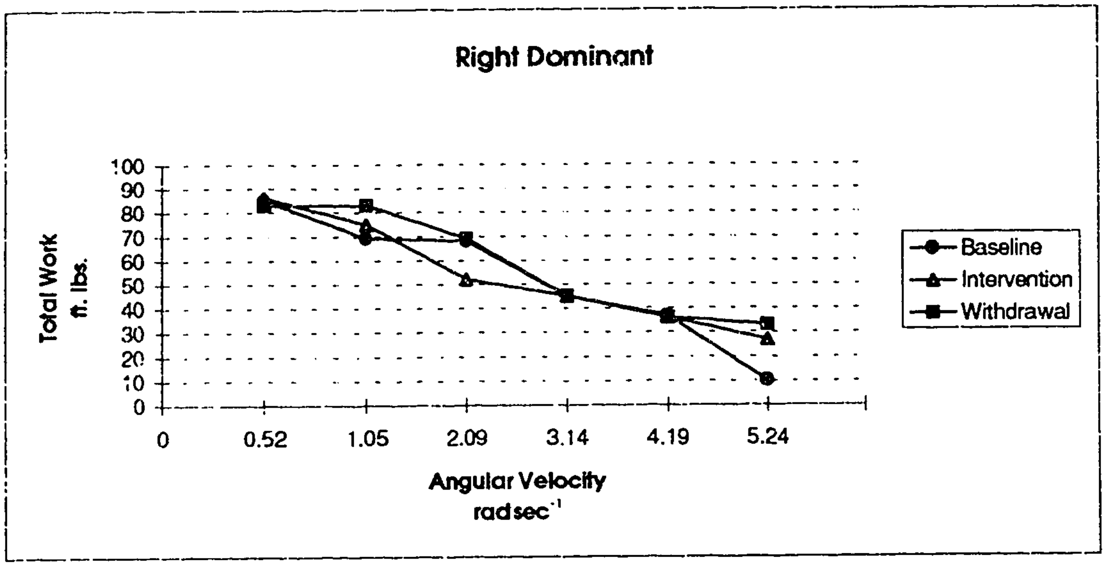


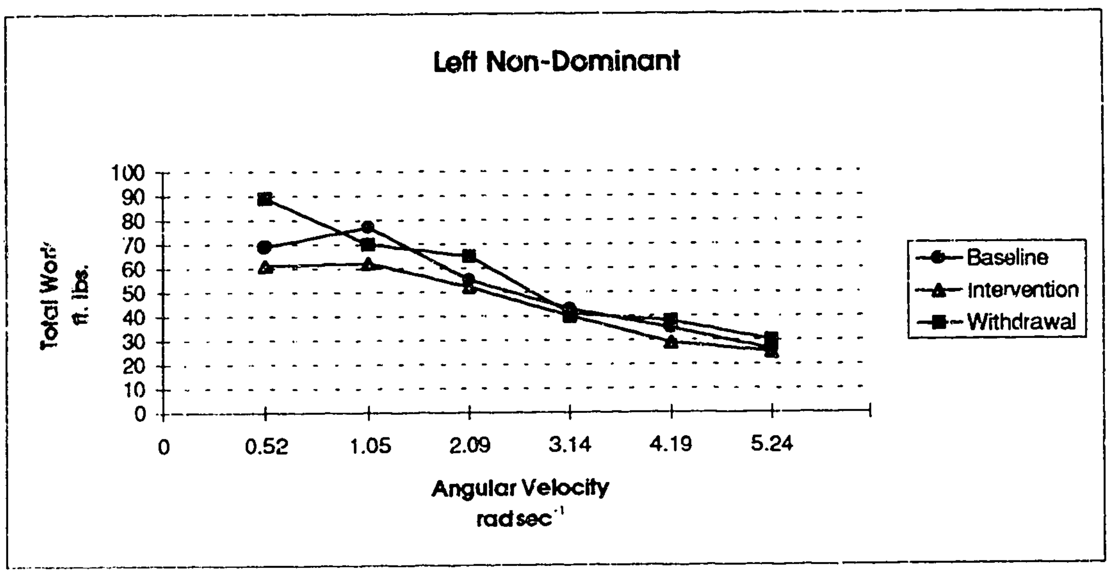
Total Work vs Angular Velocity Flexion
Subject #5



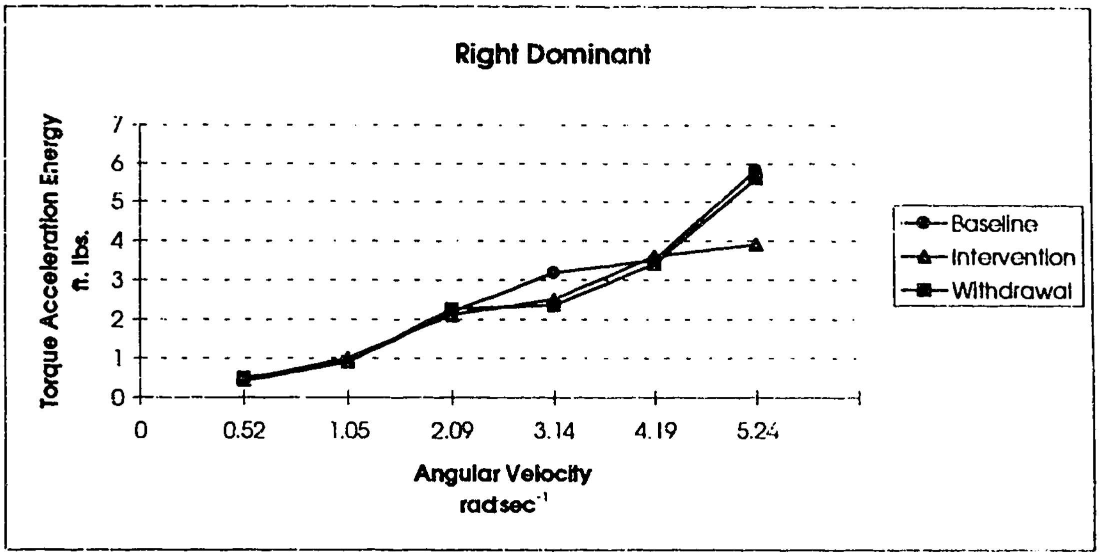


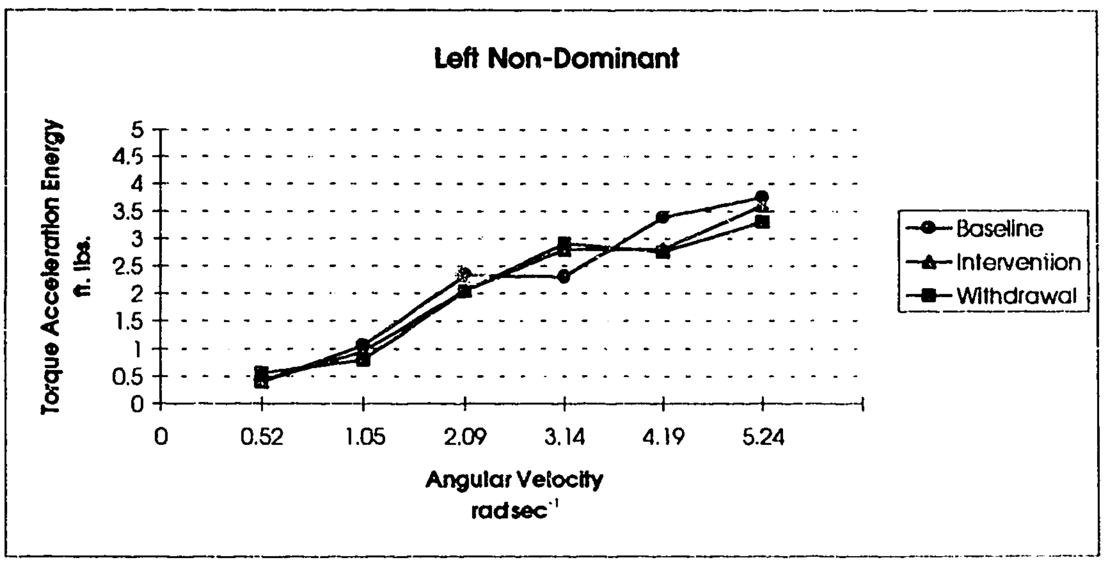
Total Work vs Angular Velocity Extension
Subject #5





Torque Acceleration Energy vs Angular Velocity Flexion
Subject #5





Torque Acceleration Energy vs Angular Velocity
Extension Subject #5