2006

Effect of repetitions on static and dynamic strength

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EFFECT OF REPETITIONS ON STATIC AND DYNAMIC STRENGTH

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science in Industrial Engineering

in

The Department of Industrial Engineering

by
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B.Tech., Jawahar Lal Nehru Technological University, 2003
May 2006

Dedicated to the people who gave my life a meaning; my Grandparents Dr.A.V.S.Reddy and Mrs.A.Prathiba for their endless love and support

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to Dr. F. Aghazadeh, my major professor for his invaluable guidance, support and advice extended to me during my period of study at LSU. He was always very helpful for any problem I had even if it was not academic related. I consider myself very fortunate to be able to work under his guidance, as I have learnt not only the basics of Human factors Engineering but also many other things which I am sure will help on many occasions in my life to come.

I also would like to thank Dr. Cornelis De Hoop and Dr. Charles McAllister for the valuable suggestions extended to me as part of the examining committee.

At this point, I wish to thank my mom, Mrs. Surekha who has worked hard to make me what I am today and hope I have made her proud and my dad, Mr. Surendranath Reddy for his immense faith in me and the endless love he has given me all through my life.

Finally, I wish to thank my best friends and support in life, Bharath and Athira without whose support I could have never completed my education here at LSU.

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ABSTRACT

The objective of this study was to investigate the effect of repetitions on static and dynamic strength. The study is divided into two parts, the first part investigated static and dynamic strength during one, three and six repetitions per minute, and the second part of the study analyzed dynamic strength data collected using the Multiaxial Multipurpose Isokinetic Dynamometer. The study comprised of dynamic strength test data at three speeds of one, five and ten inch per second.

Five male subjects participated in the first part of the study, and the results were analyzed by plotting a time series to observe the pattern of change in strength with repetitions. The results show a linear decrease in static and dynamic strength; the rate of decrease was the highest for static six repetitions per minute and the least during the dynamic one repetition per minute test. There was a decrease of 48.72% in strength for static six repetitions/minute routine and a decrease of 5.15% during dynamic one repetition per minute routine. Plot of Median Frequency (MDF) of EMG signals showed the highest rate of fatigue occurrence during static six repetition/minute and the least during dynamic one repetition/minute routine.

The results of the second part of the study also show a linear decrease in dynamic strength for the three speeds. The highest percentage decrease in strength was 15.62% during one inch per second routine, and least decrease in strength was 8.7% during the ten inch per second pull routine. During the push cycle, the highest percentage decrease in strength was 18.56% during five inch/second routine and the least decrease was 8.28% during one inch/second. Another important fact is that all subjects were able to exert a maximum strength of 64.89 lb during five inch per second pull routine. This value was

greater than the strength values exerted during one and ten inch per second push and pull routines. The MDF plot of the EMG signals showed the highest rate of fatigue occurred during five inch per second routine, and the least rate during one inch per second routine.

CHAPTER 1. INTRODUCTION

Human strength is a measure of an individual's physical capabilities, especially ones that permit a person to exert force or sustain external loading without inflicting personal injury (Mital and Das, 1987). Knowledge of worker strength is very important in designing equipment and tools to improve the human work interface (Chaffin, 1975). It is also used in screening the workers for different jobs (Chaffin and Park, 1973; Chaffin, 1974; Komon, et al., 1982; Kroemer, 1982). Determination of human strength capabilities is also necessary to design and develop engineering guidelines. Lack of design guidelines can lead to overloading of the muscle-tendon-bone-joint system and possible consequent injury (Hettinger et al., 1961). The relationship between insufficient physical capability and injury is widely admitted not only for manual materials handling activities but also for tasks requiring hand tool usage (Mital and Aghazadeh, 1985). Many methods have been developed to measure static and dynamic strengths of humans for the above mentioned purposes.

Muscle strength and endurance are two important aspects of neuromuscular performance (Heyward and McCreary, 1977). Several studies have been done to study the relation between muscle strength and endurance and the change in endurance as a function of maximum voluntary contraction. Recently, widespread attention has been devoted toward determining the relationship between maximum strength and relative muscular endurance (Shaver, 1973). Much importance has been given to measure the maximum voluntary contraction in people in designing work and workplace, but not much research has been done to find the change in strength with repetitions. Hence, the main focus of this study is to find the effect of repetitions on strength.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction to Human Strength

The central theme of ergonomics is fitting the task to the worker. This means that the workplace or any machinery and equipment should be designed considering the ability of the worker in mind. Upper body strength is frequently required for performing manual tasks in both industrial and domestic environments (Aghazadeh et al., 1997). It is hence very important to know the maximum strength capabilities of humans so as to design the different equipment to match the capabilities of the worker and to avoid injury.

Strength is the ability to produce tension. In broad terms, strength can be either static or dynamic in nature. Static muscle strength is also known as isometric muscle strength. Dynamic muscle strength can be classified as (i) isotonic (ii) isokinetic and (iii) isoinertial muscle strengths. The body segment involved and the object on which the force is exerted are stationary in static muscular exertions and there is a movement of the body segment and the object in dynamic muscular exertions. Static strength is the capacity of the muscle to produce force or torque by single maximal voluntary isometric exertion (Chaffin, 1975; Roebuck et al., 1975). Isotonic strength is the measure of a person's maximum voluntary muscle contraction in which the muscular tension is constant throughout the range of motion. Isokinetic strength is the measure of a person's maximum voluntary muscle contraction when the body segment involved in the work moves at constant speed. Isoinertial muscle strength is the measure of the person's ability to overcome the initial static resistance by measuring the maximum amount of weight the person can handle and move to an assigned point at freely chosen speed (Mital and Das, 1987).

Dynamic work is more advantageous than static work as static work leads to fatigue faster than dynamic work. In dynamic work there is movement of the muscle and this leads to oxygen transportation into the muscle and the removal of lactic acid that causes muscle discomfort and fatigue.

In the past, much research has been done to find the relationship between an individual's ability to produce maximal force and to exert submaximal forces for extended periods of time during static muscular contraction (Carlson, 1969; Carlson & McCraw, 1971; Start & Graham, 1964; Start & Holmes, 1963; Heyward, 1975; Martens & Sharkey, 1966; Noble & McCraw, 1973).

Aghazadeh et al., (1997) measured the static and dynamic strengths of males and females using a load cell and the subjects were required to exert the maximum force on the load cell and the maximum force was recorded. The procedure was repeated twice with rest between each trial. The strengths were recorded as shown in Tables 1 and 2.

Table 1. Mean Load and Standard Deviations (Kg) (Aghazadeh et al., 1997)

	Static Bicep Lift		**Static Shoulder lift**		**Static Shoulder Pull**	
	Standing	**Seated**	**Standing**	**Seated**	**Standing**	**Seated**
Male	33.83	37.31	130.55	93.80	19.58	42.79
	12.16	9.18	38.67	39.90	5.32	5.86
Female	21.22	18.38	50.60	29.26	11.39	16.62
	12.93	5.35	26.14	16.06	3.99	3.91
	Dynamic Bicep Lift		**Dynamic Shoulder lift**		**Dynamic Shoulder Pull**	
	Standing	**Seated**	**Standing**	**Seated**	**Standing**	**Seated**
Male	34.87	34.48	46.92	39.63	27.79	38.25
	12.35	15.57	12.56	6.66	21.29	18.05
Female	24.38	35.37	27.81	23.01	22.53	26.11
	14.46	17.41	9.43	4.54	17.81	18.39

Table 2. Maximum, Minimum and Mean Standing Posture Loads Expressed as a Percentage of Corresponding Seated Posture Loads. (Aghazadeh et al., 1997)

	Static Bicep Lift			**Static Shoulder lift**			**Static Shoulder Pull**		
	Max	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**
Male	109.41	40.29	90.74	211.78	72.66	138.65	60.00	30.70	48.58
Female	177.50	74.70	114.81	287.91	62.18	167.78	79.55	28.95	69.20
	Dynamic Bicep Lift			**Dynamic Shoulder lift**			**Dynamic Shoulder Pull**		
	Max	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**
Male	113.04	77.78	99.16	140.48	89.63	110.24	100.87	50.61	75.57
Female	131.58	72.73	98.11	229.73	62.07	117.72	102.75	56.88	86.85

Imrhan (1986) measured the finger strength in children, and the subjects were required to exert the maximum voluntary strength on the pinch meter and the maximum strength was noted as shown in Table 3.

Table 3. Mean S.D. and Range of Pinch Strengths (Imrhan, 1986)

Strength Type	**Mean (Kg)**		**Standard Deviation**	**Range**
Lateral Pinch	**Right Hand**	3.7	0.86	2.0-5.3
	Left Hand	3.4	0.81	1.8-5.1
Chuck Pinch	**Right Hand**	3.3	0.92	1.3-4.9
	Left Hand	3.1	0.82	1.7-4.9
Pulp Pinch	**Right Hand**			
	II	2.2	0.58	1.3-4.0
	III	2.3	0.63	1.2-3.8
	IV	1.6	0.46	0.8-2.6
	V	1.0	0.39	0.4-1.9
	Left Hand			
	II	2.1	0.59	1.2-3.5
	III	2.1	0.62	1.3-3.6
	IV	1.5	0.54	0.6-2.6
	V	1.0	0.45	0.3-2.3
Hand Grip		11.8	2.9	4.5-19.0

In a study by Fransson et al. (1991) the maximal force from each finger was measured on a pair of modified pliers. The aim of the study was to determine the effect of handles on the resultant force produced and only the maximal exerted force was measured and was concluded that the force producing ability of the hand was influenced by the grip type, and the highest resultant force was generated using the traditional grip.

Hazelton et al. (1975) measured the influence of wrist position on finger flexors in which the participants had to exert the maximum force on a digital dynamometer, and the MVC was noted at different wrist positions as shown in Table 4.

Table 4.Distribution of Force (% of total force) at Middle Phalanx in Five Wrist Positions (Hazelton et al. 1975**)**

Position	**Index**	**Long**	**Middle**	**Little**
Neutral	25.3	33.7	25.7	15.6
Volar Flexion	24.4	32.8	26.6	16.1
Dorsi Flexion	24.8	35.1	24.8	15.5
Ulnar Flexion	25.1	34.6	25.1	15
Radial Deviation	25	34.6	25.1	16
Range	13.5-36	20.9-46.9	14.7-35.4	7.3-21.6
Mean Percentage	25.4	33.9	25.2	15.2
Standard Deviation	3.6	4	4	3.2

(Magnitude of total force at the middle phalanges ranges from 31.1 to 124.2kg and at the distal phalanges the total force ranged from 17.6 to 93.3kg.)

2.2 Factors Affecting Strength

Many factors influence the strength that can be exerted. Some of the factors are

1. Training
2. Instruction
3. Fatigue

Strength is highly susceptible to training; it is a function of skill. The range among individuals is known to extend from the extreme weakness of the sedentary individual to the great muscular power found in the athlete (Morehouse, 1959). Muscle strength is also influenced by instruction Williamson et al., (1992). The study evaluated the effect of instruction on hand grip strength in males and females and re-evaluated the Caldwell Regimen for measuring grip strength. Three sets of instructions were used to evaluate the grip strength of 18 men and 17 women. The grip strength was measured using a specifically designed isometric hand grip gauge fabricated according to Mondale's design. Subjects were positioned with feet flat on the floor, back straight and supported by a backrest, shoulder adducted and neutrally rotated, elbow at 90 degrees and forearm supported in a neutral position. Subjects were asked to select a comfortable wrist position. All subjects selected a wrist angle that was between 0 and 30 degrees dorsi flexion. A minimum of three minutes rest was given between each trial. The peak forces exerted with different instructions were tabulated as shown in Table 5.

Table 5.Mean and Standard Deviations of Grip Strength (Williamson et al., 1992)

Instruction Type	Peak Force (lb)		Mean Force (lb)		Time to peak force (seconds)	
	Mean	SD	2s	3s	Mean	SD
One	84.6	25.8	82.3	81.3	2.98	1.62
Two	90.4	23.8	N/A	N/A	2.25	1.18
Three	83.8	24.8	81.6	80.8	3.77	1.27

When workers perform jobs, at some point they experience fatigue which can be either local muscle fatigue or whole body fatigue. Fatigue is basically due to the accumulation of lactic acid in the muscle. The basic source of energy for muscle contraction is glycogen. However this is not the initial source of energy. At the beginning of muscular activity, adenosine triphosphate, a high energy phosphate compound available in the muscle tissue is mobilized. It breaks down into adenosine diphosphate resulting in significant energy. If sufficient oxygen is not supplied to the muscle, pyruvic acid is converted into lactic acid while adenosine triphosphate is regenerated. Lactic acid accumulation between the muscle fibers causes muscular fatigue and pain to develop. As fatigue occurs, the ability of the muscle to contract will decrease significantly, which means the ability to exert strength will decrease significantly.

2.3 Relation between Maximum Voluntary Contraction and Endurance

In many of the strength measurement experiments researchers concentrated only on the maximum strength that can be exerted. Research has also been done to measure endurance and to analyze the relation between percentage of maximum voluntary contraction and endurance.

Tuttle et al. (1950) studied the relation between the maximum grip strength and grip strength endurance and concluded that the strength endurance is correlated with the maximum grip strength.

In a study by Garg et al. (1999) endurance time as a function of maximum voluntary contraction (MVC) was studied. The objective of this study was to determine the endurance times for a continuous hold as a function of %MVC and shoulder flexion angle. Endurance time was defined as the maximum amount of time a subject could continuously hold a given weight in a specified posture. Beyond this time the subject could no longer hold the weight due to fatigue or pain in the shoulder girdle. The results showed that endurance decreased non linearly with the increase in %MVC. The relation between endurance time and %Maximum Voluntary Contraction (MVC) was as shown in Figure 1.

Gonzales et al. (2002) performed a study on the work and fatigue characteristics of unsuited and suited humans during isokinetic motions. They measured the isokinetic torque of the subjects working at 100% and 80% of their Maximum Voluntary Torque

(MVT). The results of this study showed that the larger the MVT, the longer the time to fatigue and the greater amount of work done.

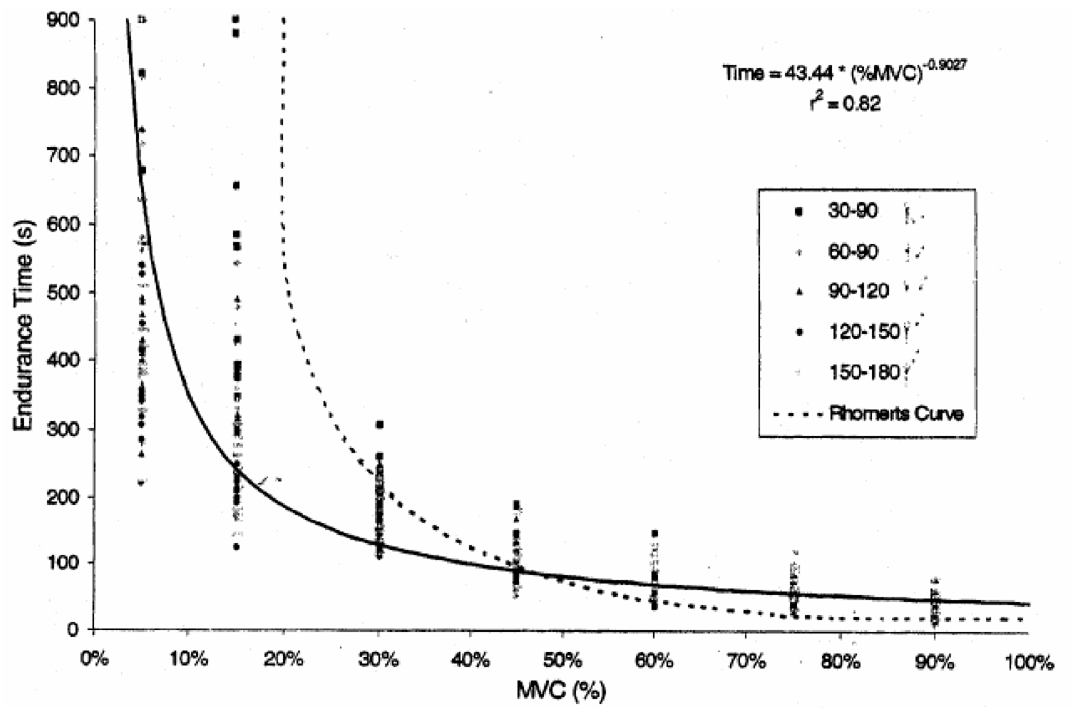

Figure 1. Endurance Time (seconds) versus %MVC

Moudgil et al. (1969) stated that maximum contraction can only be maintained for some time and the force immediately starts to decline. Royce (1958) determined that there was no appreciable drop in the maximal force of a hand grip for first 15 seconds after which it started to decline with time. Hettinger (1961) found that the maximum force of forearm flexors lasted for 10 seconds and then it started to decline.

Caldwell (1964) performed a study to determine the change in percentage maximum strength with time. In this study the subjects were required to pull as hard as possible on the handle and hold the handle for 70 seconds. The results shown in Figure 2 proved that there is an essentially linear decrease in relative strength with prolonged exertion.

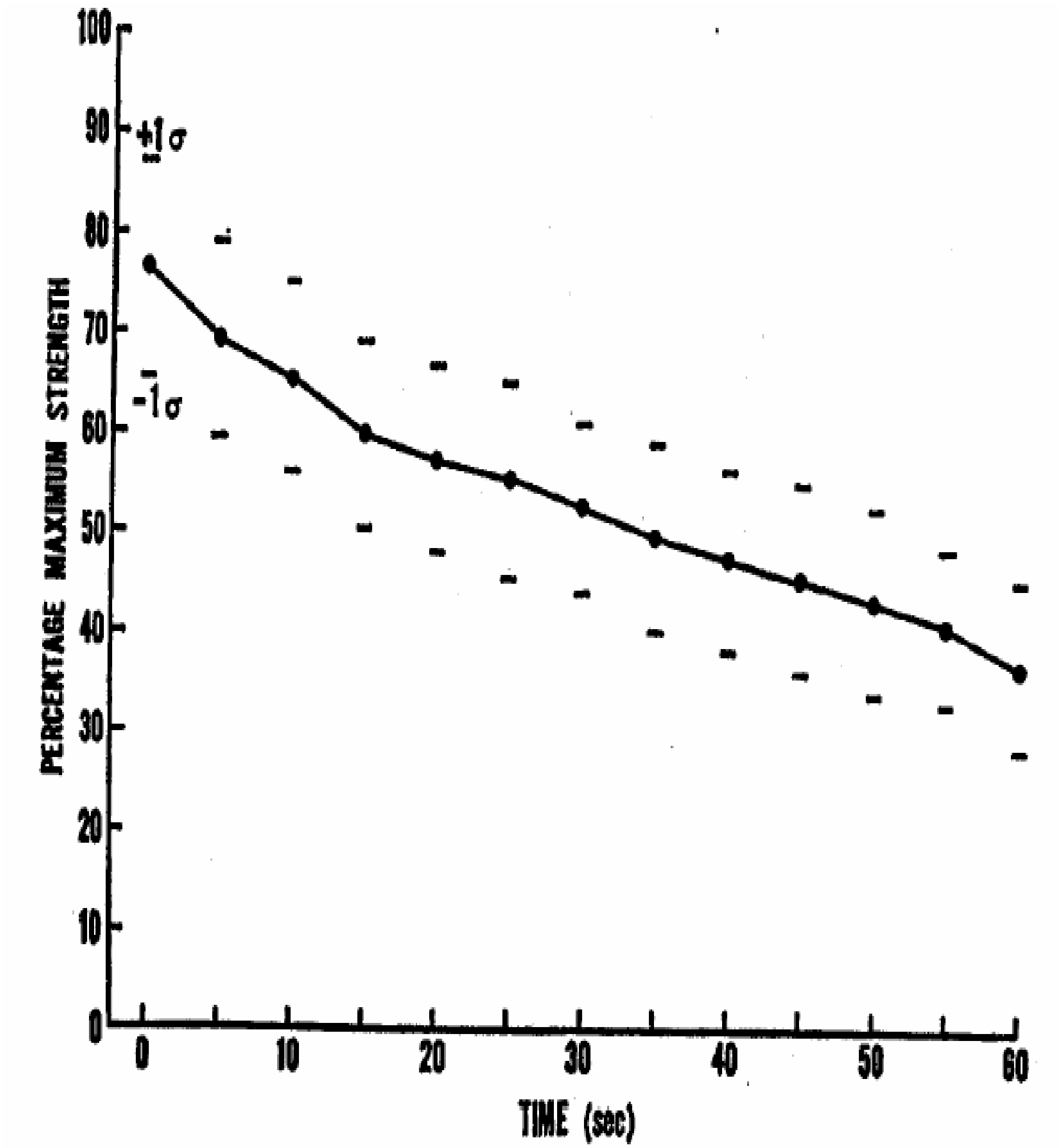

Figure 2. Percentage of Maximum Strength as Influenced by Exertion Time.

Milner et al. (1986) conducted a study to quantify muscle strength, endurance and fatigue needed in the evaluation of patients with neuromuscular disorders. The subjects were asked to exert the maximum force and maintain it for one minute. There was a linear decrease in the maximum force exerted with time as shown in Figure 3.

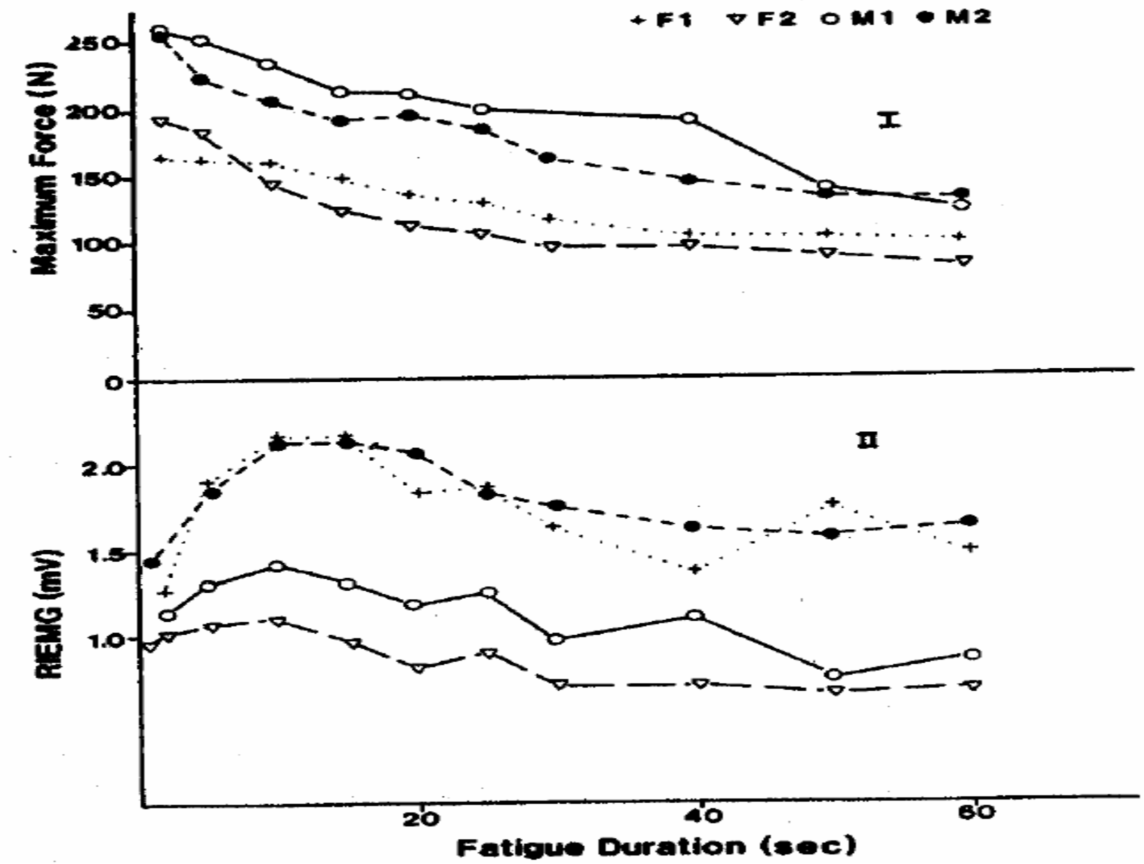

Figure 3.Time Course of Fatigue During 60seconds of Elbow Flexion. Plots Represent (I) Maximum Force and (II) Rectified/Integrated Electromyogram, from Biceps Brachii.

Sato et al. (1984) studied the relationship between force level of isometric contraction and time until muscular fatigue. Endurance tasks were performed at randomly assigned contraction levels of 5, 10, 15, 20, 30, 40 and 50% of the maximal voluntary contraction. The subjects were required to exert the force until he could not maintain the force level any longer. The duration of the sustained contraction was called the endurance time. If the endurance time exceeded 45 minutes, the contraction was terminated at 45 minutes. The time was recorded when the subject reported that he first felt "darui" (tiredness) and “itai” (pain). The relationship between endurance time and percentage MVC is shown in Figure 4 and 5.

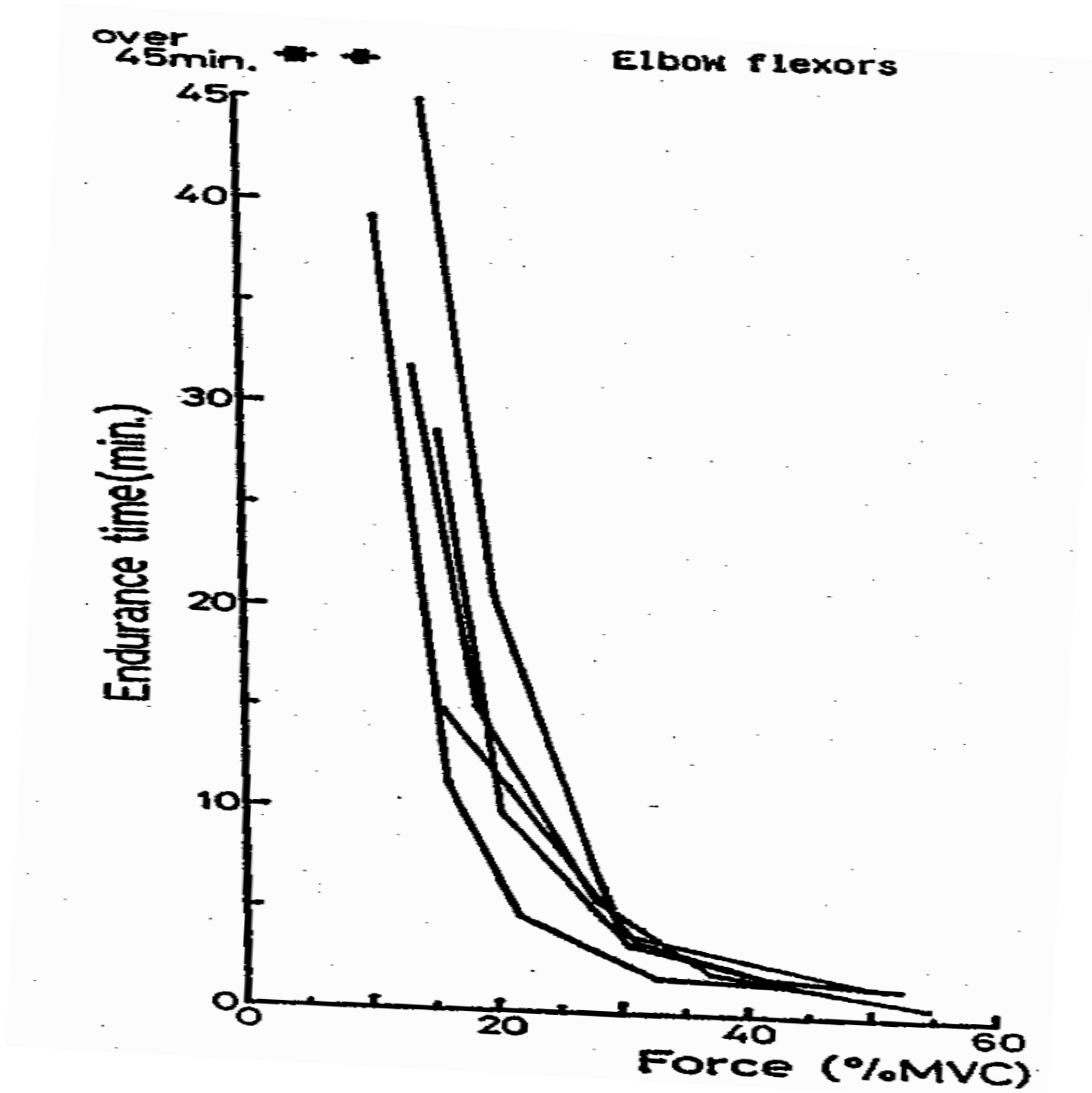

Figure 4. Endurance Time of the Five Elbow Flexors for Five Subjects

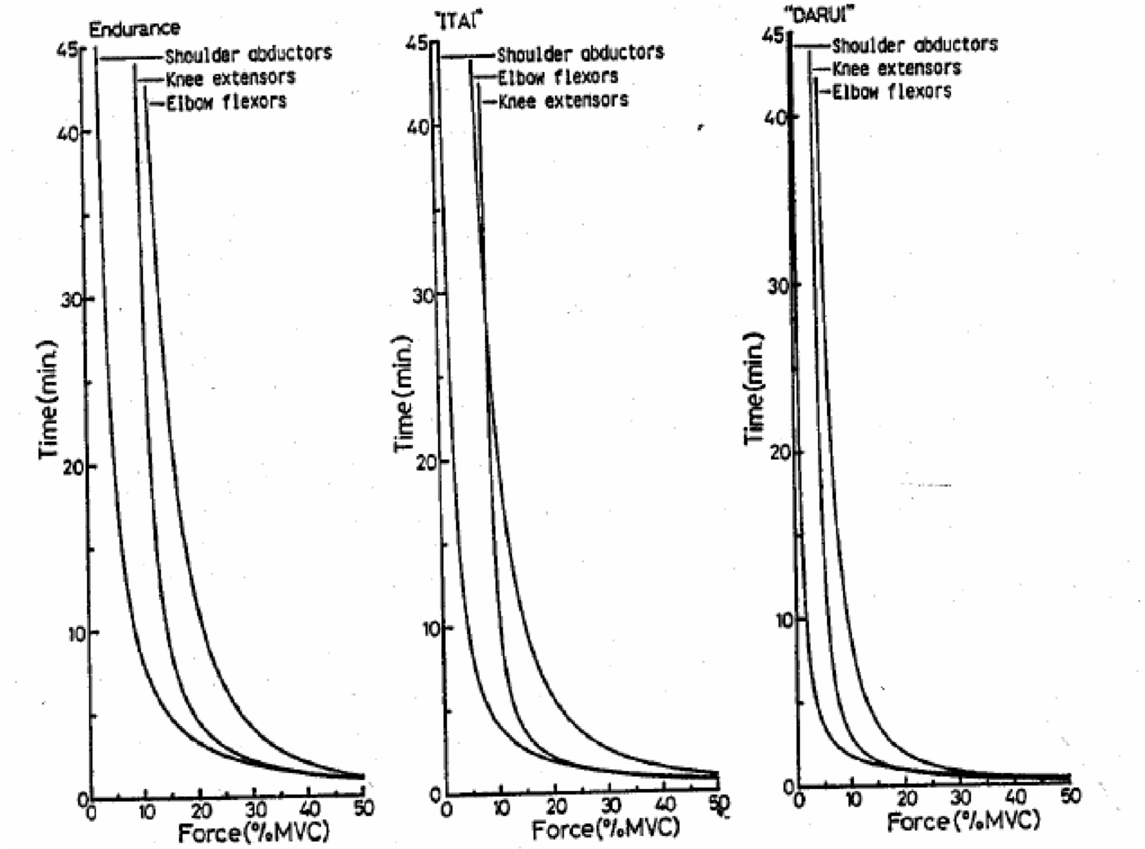

Figure 5.Relationship between the Relative Force and Time until Different Indices of Fatigue for each Muscle Group.

From the results it was concluded that the force exerted decreases with time.

2.4 Methods of Determining Fatigue

2.4.1 Heart Rate

Heart rate can be used to determine fatigue. According to Ekelund et al. (2001), the intensity of the physical activity is most commonly defined in terms of the percentages of maximal oxygen consumption, maximal heart rate, or as a multiple of resting metabolic rate. Some studies have used absolute heart rate of 140 beats per minute and 160 beats per minute to define the heart rate corresponding to moderate and vigorous intensities of physical activities (Ekelund et al., 2001, cited from Armstrong et al., 1990; Armstrong and Bray, 1991; Janz et al., 1994; Gilbey and Gilbey, 1995). The disadvantage of using this method to analyze fatigue is that it does not take into account the influences of the differences in age, gender and fitness level.

2.4.2 Subjective Rating

A popular method to assess fatigue is by using subjective rating (Borg, 1982; Bultmann et al., 2002; Wisen et al., 2002). Wisen et al. (2002) developed a one page scale based on different activity levels linked to metabolic equivalent scale.

2.4.3 Electromyography

- **Introduction to Electromyography**

Surface electromyography is a technique used to measure the various phenomena in the muscles. In biomechanics there are three applications which dominate the use of the surface EMG signal: its use as an indicator for the initiation of muscle activation, its relationship to the force produced by a muscle, and its use as an index of the fatigue processes occurring within a muscle. As an indicator of the initiation of the activity in the muscle, the signal can provide the timing sequence of one or more muscles performing a task, such as during gait or in the maintenance of erect posture. Another important application of the EMG signal is to provide information about the force contribution of individual muscles as well as groups of muscles. It is the use in the individual muscle which provides the greater attraction. The resultant muscular moment acting on a joint during a specific task is only in exceptionally rare cases due to one muscle. (The interosseous muscles of the hand, the flexor pollicis longus and the extensor pollicis are among the few that come to mind). Thus, in the vast majority of cases which are of interest, the ability to determine non-invasively the force contribution of individual muscles provides an enormous advantage, particularly when biomechanical models are developed to describe the workings of a segment of the musculoskeletal system. The use of the EMG signal to provide a fatigue index has considerable appeal because it has been shown that the signal displays time dependent changes prior to any force modification, thus having the potential to predict the onset of contractile fatigue. There are many factors that affect the quality of the EMG signal. They are:

1) The electrode configuration

2) The location of the electrode with respect to the motor points in the muscle

3) The location of the electrode on the surface of the muscle with respect to the lateral edge of the muscle

4) The orientation of the detection surfaces with respect to the muscle fibers

- **Recording Technique**

Two types of electrodes can be used to record the EMG signals, of which the surface EMG technique is much more common unless there is a specific need to use the fine wire method. Surface EMG represents the activity of individual muscles or muscle groups over which the electrodes are placed. The processed EMG signal can be used as an indication of muscle force present during exertion. As with muscle activity, the signal can be treated either in relative or absolute terms. The raw EMG signal can be processed so that fatigue information can be derived. This can be done either by observing the processed signal or by observing the change in frequency of the signal.

- **Recording of Action Potentials of the Muscles**

The basis of surface EMG is the relation between the action potentials of muscle fibres and the extracellular recording of those action potentials at the skin surface. Electrodes external to the muscle fiber can be used to detect the action potentials.

Consider two electrodes placed a considerable distance apart, directly on the surface of a muscle fiber. The electrodes are attached to an oscilloscope. In the resting stage the muscle fiber is in equilibrium and electrically positive on the outside and negative on the inside. Since the two electrodes are on the outside there is no potential difference between them. If the muscle fiber is excited to the left of the first electrode an action potential is initiated and propagated along the fiber toward the electrode. When the action potential reaches the region under the first electrode it becomes negative with respect to the second electrode and the oscilloscope deflects upward. As the action potential continues towards the second electrode, the region under the first electrode repolarizes, and the oscilloscope returns to the baseline. When the action potential is between the two electrodes, the region under the first electrode has recovered, and the region under the second electrode has not yet depolarized. The difference in potential between the electrodes is therefore zero. As the action potential moves under the second electrode this region becomes negative with respect to the first electrode, and the oscilloscope deflects downwards. The output is hence monophasic. If the two electrodes are placed sufficiently close to each other, the two waves temporally summate and form a biphasic wave. The biphasic wave is similar in appearance to the muscle fiber action potential.

- **Data Analysis Methods**

The EMG signal based on the changes in the amplitude and frequency can be quantified and used to classify the electrical activity level that produces a certain muscular tension. The change in the myoelectric signal is based on the recruitment and firing rate of motor units within the muscle. In general as more force is needed more motor units are recruited, and the motor units already firing increase their frequency of firing. This general reaction is however, not exactly the same for all the muscles (Lawrence et al., 1983). Many methods are used to reduce the data contained in the electrical signal and present it in the numerical form. The method chosen depends on the purpose of the study. The interpretation of the EMG signal plays an important part in determining the relationship of muscle activity to task performance. The basic information obtained in the myoelectric signal is

1. Whether or not the muscle is active
2. The relative amount of activity of the muscle.

This information can be combined with an observation of some kind to determine when the muscle is active, when a peak activity occurs and whether muscle fatigue has occurred.

- **Raw Signal**

The raw or the unprocessed signal is the basis of all the methods of interpreting the myoelectric activity from the muscles. By visual observation of amplitude and frequency it may be possible to identify if the muscle is relaxed or active. No current standards exist for the instrument setting and interpretive rules; therefore considerable judgment needs to be exercised in evaluation of the raw data. Such data form is of limited value and thus the signal is processed to attain a quantitative estimate that can be used for statistical or higher order analysis (Perry et al., 1981). According to DeLuca (1997), the following are the methods to analyze the EMG data:

- **Root Mean Square (RMS)**

The Root Mean Square (RMS) voltage is the effective value of the quantity of an alternating current. The true RMS value of a myoelectric signal measures the electrical power in the signal. In combination with a positive or time indicator the RMS provides an instantaneous measure of the power output of the myoelectric signal. The RMS value depends on the number of motor units firing, the firing rates of the motor units, the area of the motor unit, the motor unit duration, the propagation velocity of the electrical signal, the electrode configuration and the instrumentation characteristics (Milner et al., 1975 and Lindstrom et al., 1981). De Vries (1968) determined the efficiency of the electrical activity as a physiological measure of the functional state of muscle tissue, using the RMS values as an indication of myoelectric activity. The force and RMS values were linearly related but the slopes of the lines were different for subjects of different strengths. Lind et al. (1979) studied the myoelectric amplitude during fatiguing isometric contractions and found that RMS values were linearly related to the exerted force.

- **Integration**

The total amount of muscle activity occurring during any given interval is represented by the area under the curve during that time interval. The process for determining the area under the curve is called integration. Integrated electromyography (IMEG), evaluating the area under the curve, is a continuous evaluation of that area. The IEMG signal, therefore increases as long as any myoelectric activity is present and decreases in slope as there is less myoelectric activity. The amplitude measure at any time along the curve represents the total electrical energy summed from the beginning of the activity. Integration of the myoelectric signal provides a measure of the number of active motor units and their rate of firing. It can provide information concerning the on and off time and the relative myoelectrical activity of the muscle over a set period of time. Integration method is usually for time domain analysis of the EMG signal.

- **Frequency Analysis**

The myoelectric signal consists of a series of action potentials firing at certain frequencies. Frequency analysis decomposes the myoelectric signal into sinusoidal components of different frequencies. The frequency analysis gives the energy distribution of the signal as a function of frequency. A common use of power spectrum analysis has been the evaluation of local muscle fatigue. With a sustained muscle contraction, the high frequency components gradually decrease but the low frequency components gradually increase. This change results in a shift in the power spectrum toward the lower frequencies (De Luca, 1985).

- **Zero Crossings**

The number of times the raw signal crosses the baseline appears to be related to muscle contraction force. Within limits as the muscle activity increases the frequency increases and this results in a greater number of zero crossings.

- **Spike Countings**

The total number of spikes appearing on the oscilloscope appears to be related to the amount of muscle activity. The number of spikes increases linearly with increasing contraction force to about 70% of MVC and then levels off.

- **Turns**

The number of times the myoelectric signal changes direction is also related to the frequency of the raw signal. A turn is defined as that point where the direction of the signal changes following amplitude difference of more than 100 mv. The number of turns increases rapidly as the muscle force at low levels increases but increases very slowly at high levels of muscle force. The number of turns reaches its maximum before the maximum muscle force is reached. Turn analysis discriminates well between low level muscle forces but it discriminates poorly at high levels (Gilai, 1987).

Lindstrom et al. (1977) found that the EMG power spectrum shifts to lower frequency bands during the development of muscle fatigue. The time-dependent shift in mean power frequency of EMG signals to lower frequencies during the fatigue process is a proven and well established phenomenon, and hence this method is used in this study.

CHAPTER 3. RESEARCH RATIONALE AND OBJECTIVES

Many tasks require force to be exerted in order to perform critical activities. The force being exerted may be either static or dynamic in nature. Hence, the determination of human strength exertion capabilities is very important in the development of ergonomic guidelines and for pre-employment screening of workers performing manual jobs. Many methods have been developed to measure the Maximum Voluntary Contraction in both static and dynamic tasks.

An important factor to be considered is fatigue. Fatigue basically occurs due to the accumulation of lactic acid in the muscle. Lactic acid is the waste produced in the muscle. When a muscle works over a period of time without adequate rest, lactic acid is accumulated in the muscle which causes fatigue. As fatigue occurs the performance of muscle decreases. Hence, it is important to determine the change in strength with the repetition of any task. According to Mital et al. (1986) repetitive dynamic strength is a more accurate measure of an individual's lifting capacity for frequently performed tasks than maximal static or dynamic strengths.

Caldwell (1964) in his study to measure the static muscle endurance concluded that the relative strength decreases linearly with prolonged exertion.

Moudgil et al. (1969) from their research concluded that maximum contraction can only be maintained for some time, and the force immediately starts to decline.

According to Mital et al. (1987) screening procedures based on repetitive dynamic strengths for moderately frequent lifting tasks (up to once per minute) should be used in screening of workers rather than the use of either isometric or maximal dynamic strengths. Hence, it is important to determine the effects of repetition on strength.

Research has been done to investigate the maximal strength of a person and also to find the relation between endurance and time; but not on the effects of repetition on strength. The aim of this study is to find a relation between the repetitions and the strength at various frequencies and to analyze strength data collected using a Multipurpose Multiaxial Isokinetic Dynamometer (MMID).

3.1 Objectives

The study is composed of two parts. The aim of part I was to study the effect of repetitions on static and dynamic strength. The purpose of Part II of the study was to analyze the dynamic strength data collected using a Multipurpose Multiaxial Isokinetic Dynamometer (MMID). The specific objectives of this study were:

3.1.1 Objectives of Part-I

- To determine the rate of decrease of static and dynamic strength's with repetitions.
- To determine the trend of the change in strength with repetitions.
- To determine the fatiguing characteristics of the muscles using EMG data collected during the study.
- To compare the rate of change of static and dynamic strengths with repetitions.
- To compare the effect of number of repetitions on static and dynamic strengths.

3.1.2 Objectives of Part-II

- To analyze the dynamic strength data collected using a MMID.
- To study the change in dynamic strength with repetitions.
- To compare change in dynamic strength with repetitions at different speeds.

- To determine the fatiguing characteristics of the muscles using EMG data collected during the study.

CHAPTER 4. METHODS AND PROCEDURES

4.1 Methods and Procedures of Part-I

4.1.1 Subjects

Five (5) young males participated as subjects in this study. The subjects did not have any history of medical problems which would have impaired their ability to perform the strength tests. Anyone with such a problem was excluded. Height and weight of each participant were measured.

The experimental procedure was explained in detail to each participant before the experimental session. Table 6 shows the mean and standard deviation of the anthropometric data of the subjects.

Table 6. Anthropometric Data of Subjects

	Mean	**Standard Deviation**
Age(Years)	21.8	1.48
Height(Inches)	68.84	0.97
Weight(Lb)	169.8	11.09

4.1.2 Equipment

The equipment used in this study were the Dillon Load Cell (Weigh-Tronix Inc., MN, USA) to measure the static strength and MINIGYM (Health and Fitness Systems Inc., MO, USA) to measure the dynamic strength. A stopwatch was used to measure the rest periods between each successive repetition. A handheld, battery-operated Bagnoli 2-channel EMG system (DelSys Inc., Boston, MA) was used to measure the EMG activity of the bicep muscle of the subjects.

4.1.3 Experimental Design

Part I of the experiment was divided into two sessions. The first session was to measure the change in static strength with repetitions and the second session of the experiment was to determine the change in dynamic strength with repetitions. Each session of the experiment was repeated with a change in the number of repetitions and the repetitions were continued for a period of 420s. There was at least a 24 hour rest period between the two sessions. The strength values measured in this study were the dynamic arm lift and the static arm lift.

- **Static Arm Lift**

The handle of the equipment was adjusted such that the forearms of the subject were flexed at 90 degrees and the upper arms were vertical, parallel and adjacent to the torso. The subject was required to stand erect, with legs and back straight and with flat feet as shown in Figure 6. The subject was then required to hold the sides of the handle bar connected to the load cell and exert the force upward and vertically in the sagittal plane. The exerted force was generated by the arms only and any shoulder movement was avoided. The procedure was repeated for one repetition per minute, three repetitions per minute and six repetitions per minute.

- **Dynamic Arm Lift**

The handle of the equipment was adjusted such that the forearms of the subject were flexed at 90 degrees and the upper arms were vertical, parallel and adjacent to the torso. The subject was required to stand erect, with legs and back straight and with flat feet. The subject was then required to hold the sides of the handle connected to the MINIGYM and pull the handle in the sagittal plane as shown in the Figure7. The exerted force was generated using the arms only and any shoulder movement was avoided. The procedure was repeated for one repetition per minute, three repetitions per minute and six repetitions per minute.

The strength was recorded for every repetition from the display unit. The repetitions in each session were continued for a period of 420sesonds.

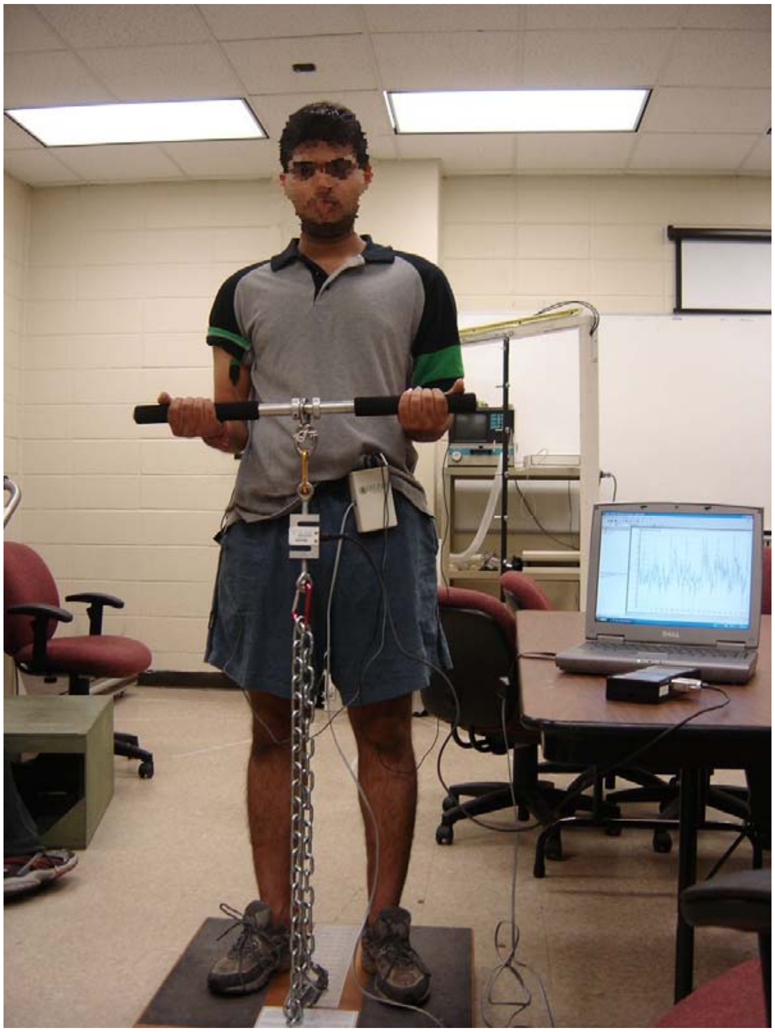

Figure 6. Static Strength Testing

Figure7. Initial and Final positions during Dynamic Strength Testing

4.2 Methods and Procedures of Part-II

4.2.1 Subjects

Ten (10) male volunteer employees of NASA-Johnson Space Centre, Houston, Texas, participated as subjects in this study. Height and weight of each participant were measured. Table 7 shows the mean and standard deviation of the anthropometric data of the subjects.

Table 7. Anthropometric Data of Subjects

	Mean	Standard Deviation
Age(Years)	37.7	10.3
Height(Inches)	70.1	2.4
Weight(Lb)	181.6	34.1

4.2.2 Equipment

The apparatus used in this project was a Multipurpose, Multiaxial Isokinetic Dynamometer (MMID). The Multipurpose Multiaxial Isokinetic Dynamometer (MMID) is a type of dynamometer used for measuring and stressing muscles in the arms, legs, and trunk. It monitors both strength and limb position in 3-D space. The key components of the MMID are the eight active modules. The modules reel in or spool out cable in unison to achieve a desired trajectory of the end effector. The MMID is capable of achieving complex, six degree-of-freedom motions by using all eight active modules. With all eight modules maintaining a given position, the end effector can be rigidly fixed in space. Other advantage of the machine is the fact that each module is light (7 pounds) and requires almost minimum volume when stored (7 x7x7 inches).

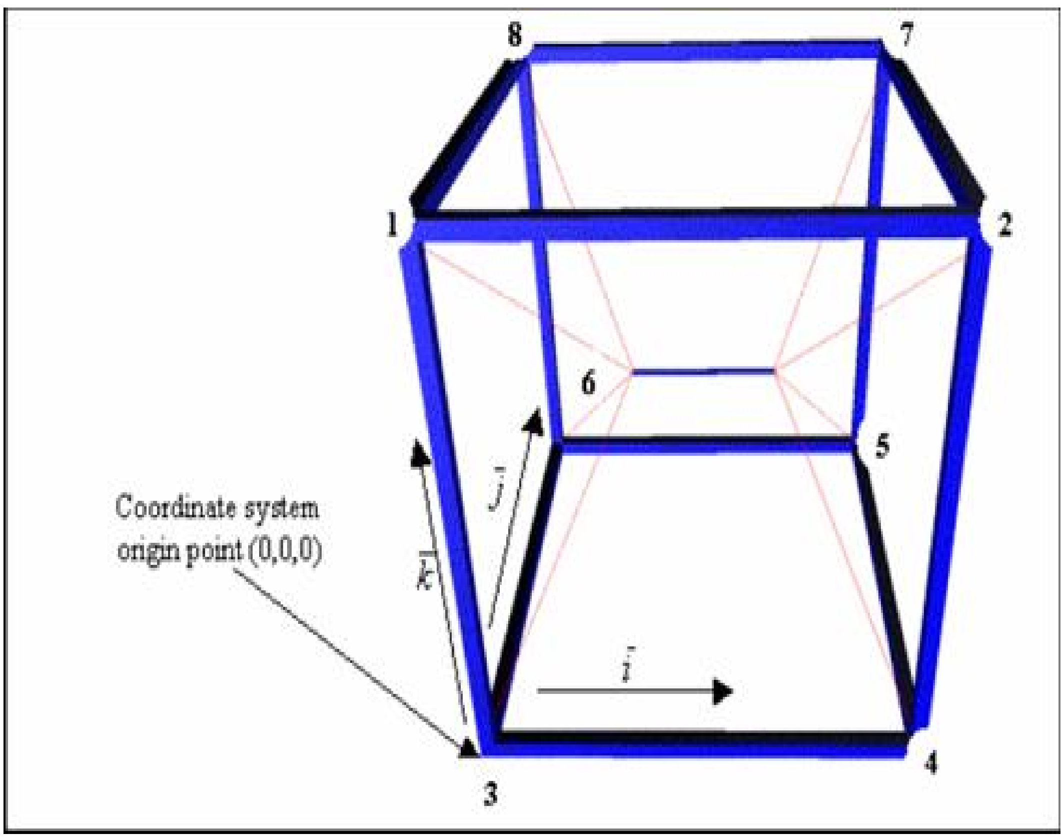

Figure 8. System Configuration and Coordinate Conventions

A diagram of the MMID system in its typical configuration is shown in Figure 8. This Figure shows the cubic configuration, the coordinate system origin point and orientation, and a typical end effector configuration (a bar). There are eight cables attached to eight points on the end effector, four points on each end. This configuration enables a comfortable balance between range of motion and force generating capability. Figure 9 illustrates one of the eight modules (pods).

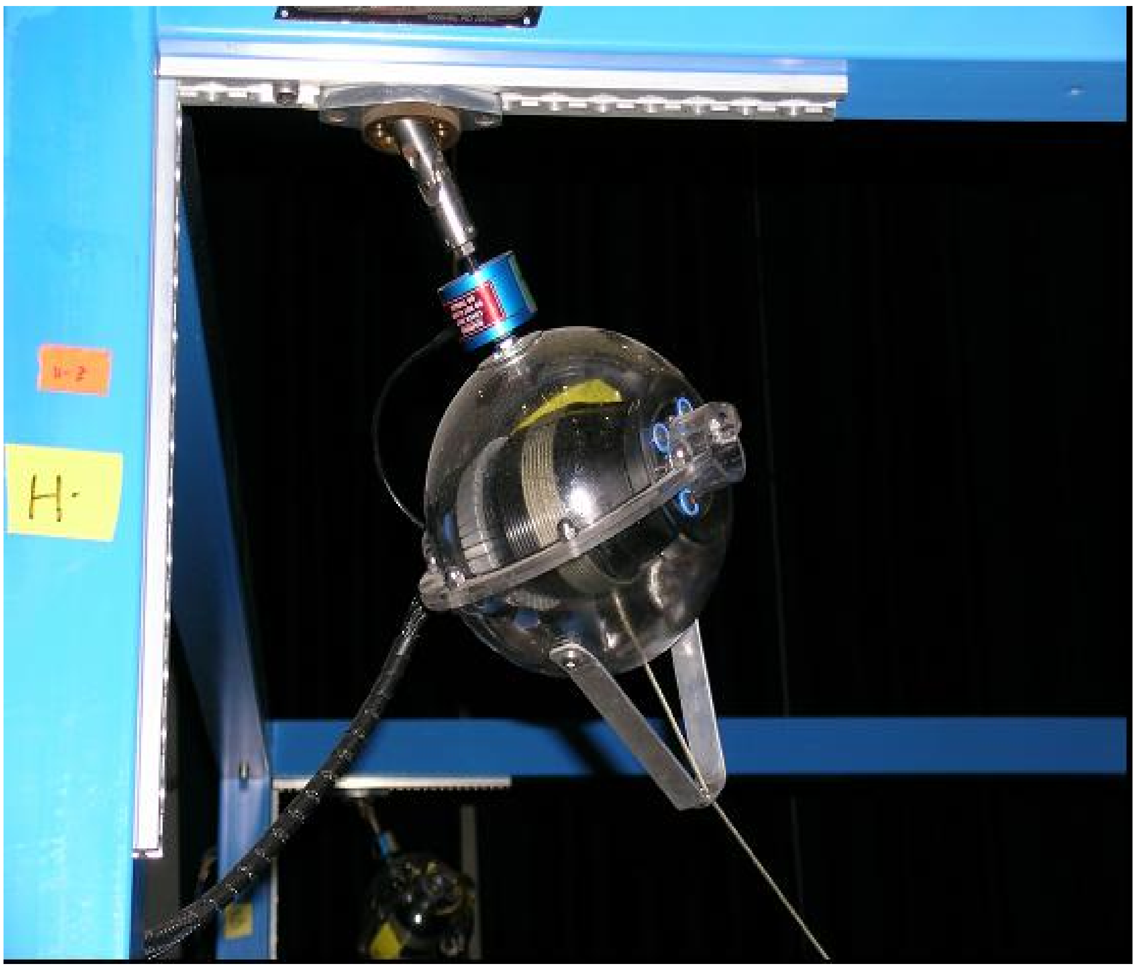

Figure 9. An Illustration of a Module (Pod)

Some measurement capabilities of MMID are listed below and are shown in Figure 10 (Real-time Display Window) and Figure 11 (Real-time Information Display Window):

- Continuous recording of effector position in X,Y,Z axis

- Continuous recording of force (lbs), speed (in/s), acceleration (in/s^2), deceleration and moment.

The apparatus is capable of measuring forces for the following routines:

- Squat
- Bench Press
- Incline shoulder Press
- Vertical Leg Press
- Calf raises
- Lat Pull-down (Latissimus dorsi)
- Military Press
- Bent-over Row
- Butt Blaster
- Inclined Leg Press
- Triceps Press-down
- Standing Curl
- Cup Lift
- Roto-swirl
- Leg Curl
- Seated Curl
- Inverted Push-up
- Single Pod Pull
- Bowl Move

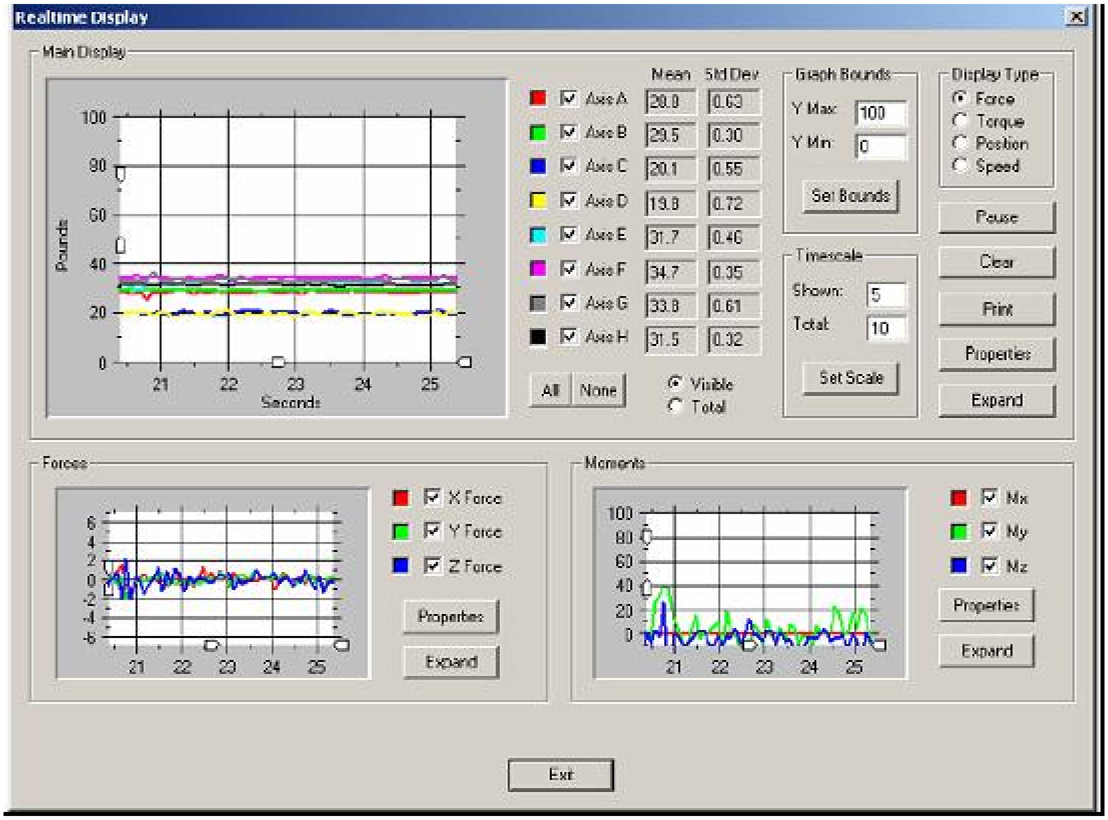

Figure 10. Real-time Display Window

Figure 11. Real-time Information Display Window (Force in lbs.)

4.2.3 Experimental Protocol

The selected routine was the push-pull routine at speeds of one, five, and ten inch/s. The triceps muscle was selected for the electrode location. The EMG recording devise was the Bagnoli-2 EMG System (DelSys Inc., Boston, MA). This is a handheld, battery-operated 2-channel EMG system. The participants were asked to sit on the MMID bench and push the effector as hard and as fast they could without jerking the bar. The participants repeated the routine at the prescribed speed of one, or five, or ten inch/s for 400 seconds. Data was collected and recorded for analysis.

4.3 Methods of Analyzing the Collected Data

4.3.1 Methods of Analyzing Part-I

The aim of the study was to study the change in strength with repetitions with a constant rest period between each successive repetition.

- **Dependant Variables**

Strength: Strength was measured after every repetition.

Change in EMG: The changes in the EMG values were noted.

- **Independent Variables**

Number of repetitions: The number of repetitions was the independent variable. The number of repetitions in this study was one, three and six repetitions per minute.

Duration: The time period for the experiment was kept constant for a period of 420s.

The results were analyzed by plotting a time series and a regression analysis was done to observe the pattern of change in strength with repetitions. The collected EMG readings were analyzed using the Median Frequency analysis to determine the fatiguing characteristics of the muscles.

- **Statistical Analysis**

A paired comparison T-test was done between the initial strength value (strength at the start of the experiment) and the strength value at the end of the experiment for all the sessions at 95% confidence interval.

4.3.2 Methods of Analyzing Part-II

The results were analyzed by plotting a time series and a regression analysis was done to observe the pattern of change in strength with repetitions. The MMID collected the data for every 0.016s and hence there were a large number of readings. The highest three readings in each of the repetition were determined if they are within 15% of each other and the average of the three readings was calculated. This average value was taken as the strength value of that particular repetition. The same procedure was followed for all the repetitions and a time series was plotted to determine the pattern of change in strength.

- **Statistical Analysis**

A paired comparison T-test was done between the initial strength value (strength at the start of the experiment) and the strength value at the end of the experiment for all the sessions at 95% confidence interval.

4.4 EMG Analysis

Lindstrom et al. (1977) found that the EMG power spectrum shifts to lower frequency bands during the development of muscle fatigue. Basmajian and De Luca (1985) indicated that the firing rates of the motor units decrease during constant force contractions and this decrease in the firing rate will decrease the amplitude of the EMG signal and also cause a spectral shift of the signal. There are several different techniques for processing EMG, however, the development of fatigue can be observed by amplitude and spectral analysis of EMG readings.

The time-dependent shift in mean power frequency of EMG signals to lower frequencies during the fatigue process is a proven and well established phenomenon and hence this method was used in this study. The spectral modification may be monitored and quantified by tracking some characteristic indicators of the frequency spectrum, such as the median, mean or mode frequency of the spectrum, or alternatively by calculating a ratio of a low-frequency to high-frequency bandwidths, or by integrating the area corresponding to the decrease of the median frequency.

There are two main properties of the EMG signal that can affect the frequency spectrum:

1) The firing behavior of the muscle motor units

2) The shape of the Motor Unit Action Potentials (MUAP).

The variance of the firing rates will determine the broadness of the frequency peak representing the firing rate. If one observes the shape of the compound action potential of a muscle during a sustained contraction, it will be seen that the time duration of the action potential increases as the time of the contraction increases. It can be shown mathematically that this behavior of the motor unit action potential shape would cause a compression in the spectrum of the EMG signal (De Luca, 1997).

The change in the firing behavior and the shape of the motor unit action potentials of the muscles affect the frequency spectrum of the EMG signal and hence cause a shift in frequency when fatigue occurs.

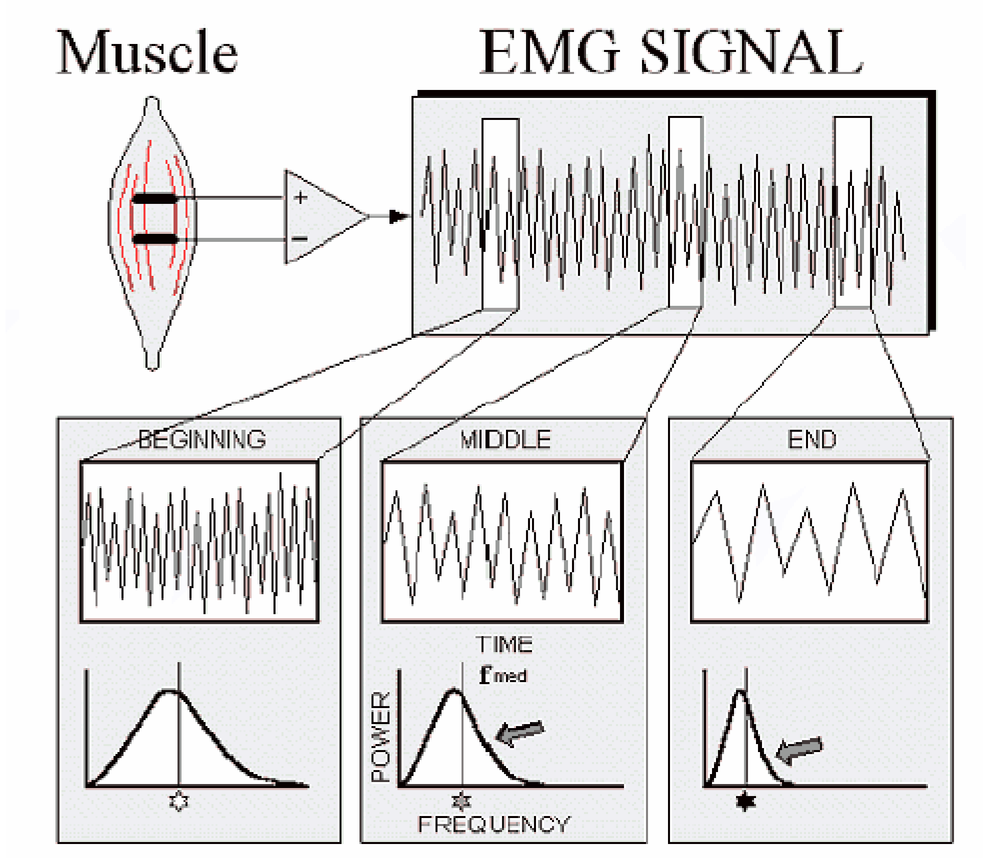

Figure 12. A Diagrammatic Explanation of the Spectral Modification which Occurs in the EMG Signal during Sustained Contractions (DeLuca, 1997)

4.5 Expected Results

4.5.1 Hypothesis

The static and dynamic strengths exerted by subjects will decrease with repetition.

The dependency of strength on repetition was explored in this study. The findings of Moudgil et al. (1969), Kroemer et al. (1970) and Monod, (1985) who conducted studies to determine the change in static strength with time show a linear decrease in maximum contraction. Hence, we expect the strength to decrease with repetitions. Also we expect the strength to decrease linearly with repetition in both static and dynamic work.

CHAPTER 5. RESULTS

The strength from Part I and II of the study is tabulated and presented in this section. Various graphs depict the change in strength with repetitions. In general, the time series plotted for the collected data demonstrate that there is a linear decrease in both static and dynamic strength for all the participants. Spectral analysis of the recorded EMG signal shows the progressing fatigue with ongoing repetitions.

5.1 Results of Part-I

Tables 8, 9 and 10 show the average dynamic and static strengths of all the subjects for one, three and six repetitions per minute and the percentage decrease in static and dynamic strength for each of the repetitions, respectively. Figures 13 and 14 show the time series plotted for the average dynamic and static strength of all the subjects for one, three and six repetitions per minute routines.

An important factor observed is that, although there is a decrease in strength linearly for both static and dynamic types of strength, the total amount of decrease in strength is greater during static exertion than dynamic exertion. As shown in Table 10, during dynamic one repetition per minute test, the total reduction in strength is 5.15 percent whereas the total reduction in strength for one repetition per minute static is 16.2 percent. The same trend is observed for three and six repetitions per minute routines also. Figures 13 and 14 show that the strength decreased linearly for both static and dynamic testing.

The rate of decrease of strength is the highest for static six repetitions per minute and least for dynamic one repetition per minute. The rate of decrease of strength is greater for static exertions rather than dynamic exertions for all the three number of repetitions.

5.1.1 Strength Test Values at One Repetition per Minute

- **Static Strength**

Static strength during one repetition per minute decreases from an initial value of 64.18lb to 40.74lb by the end of 420 seconds. The overall decrease is 16.2 percent and there is a decrease of 2.02 percent in strength for every repetition. As shown in Figure 14, it is evident that the strength decreases in a linear fashion and from the slope it is found that the rate of decrease in strength is the least when compared to three and six repetitions per minute.

- **Dynamic Strength**

Dynamic strength during one repetition per minute decreases in a linear fashion from an initial value of 54.74lb to 51.92lb over a period of 420 seconds. The over all percentage decrease in strength is 5.15 percent and the percentage decrease in strength per repetition is 0.64 percent. The rate of decrease in strength is less compared to static strength. As shown in Figure 13, the rate of decrease of dynamic strength for one repetition per minute is the least when compared to three and six repetitions per minute.

5.1.2 Strength Test Values at Three Repetitions per Minute

- **Static Strength**

There is a decrease from an initial value of 63.5lb to 53.78lb by the end of 420 seconds during static three repetitions per minute strength testing routine. The overall decrease is 35.84 percent and there is a decrease of 1.62 percent in strength for every repetition. As shown in Figure 14, the strength decreases in a linear fashion and the rate of decrease in strength is greater than one repetition per minute routine but less than six repetitions per minute routine.

- **Dynamic Strength**

Dynamic strength decreases from an initial value of 52.2lb to 40.86lb over a period of 420 seconds during one repetition per minute test. The over all percentage decrease in strength is 21.72 percent and the percentage decrease in strength per repetition is 0.98 percent. The dynamic strength also decreases in a linear fashion similar to static strength, but the rate of decrease in strength is less compared to the static strength. As shown in Figure 13, the rate of decrease of dynamic strength for three repetitions per minute is greater than one repetition per minute but less than six repetitions per minute.

5.1.3 Strength Test Values at Six Repetitions per minute

- **Static Strength**

Static strength during six repetitions per minute decreases from an initial value of 64.36lb to 33lb by the end of 420 seconds. The overall decrease is 48.72 percent and there is a decrease of 1.13 percent in strength for every repetition. As shown in Figure 14, the strength decreases in a linear fashion and by calculating the slope it is found that the rate of decrease in strength is the greatest during six repetitions per minute.

- **Dynamic Strength**

Dynamic strength decreases from 49.84lb to 37.7lb over a period of 420 seconds during six repetitions per minute. The dynamic strength also decreases in a linear fashion similar to static strength, but the rate of decrease in strength is less compared to static strength. The over all percentage decrease in strength is 24.35 percent and the percentage decrease in strength per repetition is 0.56 percent. As shown in Figure 13, the rate of decrease of dynamic strength for six repetitions per minute is the highest compared to the other two routines.

Table 8. Average Dynamic Strength of Subjects

Time	**Average Strength(lb) 1 Rep/Min**	**Average Strength(lb) 3 Reps/Min**	**Average Strength(lb) 6 Reps/Min**
0	54.74	52.2	49.84
60	53.68	51.58	48.58
120	54.56	46.84	47.98
180	53.52	48.94	43.74
240	52.64	45.62	46.12
300	52.54	44.02	39.52
360	51.74	43.22	39.62
420	51.92	40.86	37.7

Table 9. Average Static Strength of Subjects

Time	**Average Strength(lb) 1 Rep/Min**	**Average Strength(lb) 3 Reps/Min**	**Average Strength(lb) 6 Reps/Min**
0	64.18	63.5	64.36
60	60.12	57.46	51.6
120	58.46	58.36	56.66
180	58.34	53.48	52.34
240	58.64	51.24	50.18
300	56.22	46.14	37.62
360	54.7	42.58	34.04
420	53.78	40.74	33

Table 10. Percentage Decrease in Static and Dynamic Strength during Different Routines(lbs)

Routine	Start Strength	End Strength	Total % Decrease in Strength	No. of Repetitions	Generalized Equation
Dynamic 1 rep/min	54.74	51.92	5.15	8	y=-0.4331x+55.116
Dynamic 3 rep/min	52.2	40.86	21.72	22	y=-1.5829x+53.783
Dynamic 6 rep/min	49.84	37.7	24.35	43	y=-1.8188x+52.322
Static 1 rep/min	64.18	53.78	16.20	8	y=-1.2657x+63.75
Static 3 rep/min	63.5	40.74	35.84	22	y=-3.2455x+66.292
Static 6 rep/min	64.36	33	48.72	43	y=-4.3643x+67.114

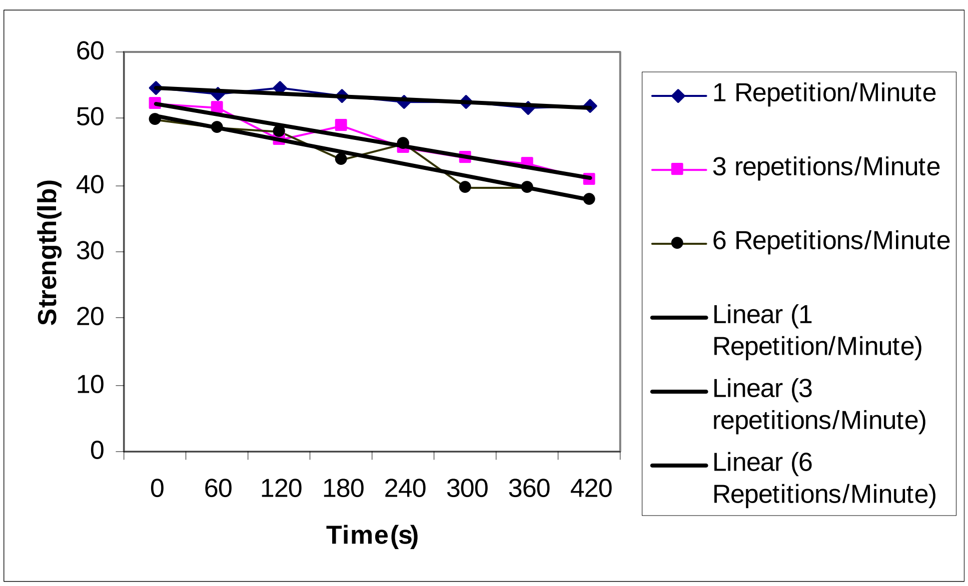

Figure 13. Average Dynamic Strength versus Time of Subjects

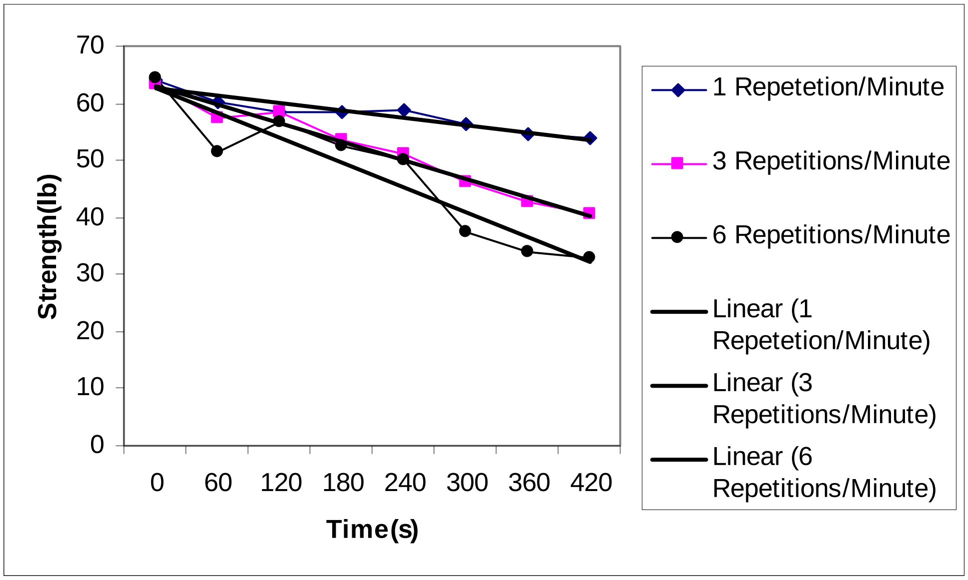

Figure 14. Average Static Strength versus Time of Subjects

5.2 Results of Part-II

Table 11 shows the average pull and push strength of all the subjects for one, five and ten inch/sec speeds and the percentage decrease in strengths for all subjects. Table 12 summarizes the total percentage decrease and percentage decrease in strength for each cycle for one, five and ten inch/second speeds of strength testing routines. The number of repetitions or cycles is the least for one inch per second and highest for ten inch per second. Figure 15 and 16 show the average pull and push strength of all the subjects for one, five and ten inch per second speeds of dynamic strength testing routines.

The number of repetitions in this study is not constant and the lowest is for the speed of one inch per second speed cycle and the highest is for the ten inch per second cycle. There are fourteen repetitions for one inch per second pull routine, thirteen repetitions for one inch per second pull cycle, forty three repetitions for five inch per second pull routine, forty four repetitions for five inch per second push routine and fifty three repetitions for ten inch per second push and pull routines. The maximum decrease in strength occurs during the one inch per second routine and the lowest decrease during the ten inch per second routine, respectively and strength decreased in a linear fashion for all the three speeds, the rate of which is highest during one inch per second followed by five inch per second and ten inch per second, respectively.

5.2.1 Dynamic Strength Values for One Inch per Second Routine

- **Dynamic Strength Values for Pull Cycle**

The average strength of the subjects decreases from an initial value of 57.79lb to 48.76lb, which is a decrease of 15.62 percent. There are fourteen repetitions during this routine and the percentage decrease in strength for each cycle is 1.11 percent. As shown in Figure 15 strength decreases in a linear fashion and the rate of decrease is higher than the other two speeds.

- **Dynamic Strength Values for Push Cycle**

There is a decrease in average strength of the subjects from an initial value of 58.3lb to 53.47lb; a decrease of 8.28 percent. There are thirteen repetitions during this routine and the percentage decrease in strength during each cycle is 0.63 percent. As shown in Figure 16, strength decreases in a linear fashion and the rate of decrease is higher than five and ten inch per second speed tests.

5.2.2 Dynamic Strength Values for Five Inch per Second Routine

- **Dynamic Strength Values for Pull Cycle**

The average decrease in strength of the subjects is from an initial value of 64.89lb to 59.99lb, a decrease of 13.71 percent. There are forty three repetitions during this routine and the percentage decrease in strength during each cycle is 0.31 percent. As shown in Figure 15, strength decreases in a linear fashion and the rate of decrease is lower than one inch per second but greater than the ten inch per second. An important finding is that, the subjects are able to exert the maximum strength under this speed condition when compared to the other two routines. The average push strength exerted is 59.95lb and pull strength is 64.89lb.

- **Dynamic Strength Values for Push Cycle**

The average strength of the subjects decreases from an initial value of 59.95 to 48.82lb, a decrease of 18.56 percent. There are forty four repetitions during this routine and the percentage decrease in strength during each cycle is 0.42 percent. As shown in Figure 16, strength decreases in a linear fashion and the rate of decrease is lower than one inch per second but greater than the ten inch per second. An important finding is that, the subjects are able to exert the maximum strength under this speed condition when compared to the other two conditions. The average push strength exerted is 59.95lb and pull strength is 64.89lb.

5.2.3 Dynamic Strength Values for Ten Inch per Second Routine

- **Dynamic Strength Values for Pull Cycle**

There is a decrease in the average strength of the subjects from 60.57lb to 55.25lb, a decrease of 8.7 percent. There are fifty three repetitions during this routine and the percentage decrease in strength during each cycle is 0.16 percent. As shown in Figure 15, strength decreases in a linear fashion and the rate of decrease is the least compared to one and five inch per second speed tests.

- **Dynamic Strength Values for Push Cycle**

The average strength of the subjects decreases from 53.89lb to 48.45lb, a decrease of 10.09 percent. There are fifty three repetitions during this routine and the percentage decrease in strength during each cycle is 0.19 percent. As shown in Figure 16, strength decreases in a linear fashion and the rate of decrease is the least compared to one and five inch per second speed tests.

Table 11. Average Pull and Push Strength of Subjects for 1, 5 and 10 Inch/Sec Strength Testing Cycles

Cycle	Average Strength(lb) 1 inch/sec		Average Strength(lb) 5 inch/sec		Average Strength(lb) 10 inch/sec	
	Pull	**Push**	**Pull**	**Push**	**Pull**	**Push**
1	57.79	58.3	64.89	59.95	60.57	53.89
2	56.45	56.06	65.23	59.05	62.44	56.38
3	56.56	54.65	68.14	56.48	61.15	54.26
4	56.82	56.62	69.75	56.66	66.26	55.23
5	56.80	55.71	68.40	60.38	65.85	53.05
6	55.14	53.16	66.94	62.52	63.11	56.58
7	53.92	55.58	68.16	59.72	63.99	55.76
8	51.85	52.31	67.58	60.61	64.38	55.95
9	51.63	57.31	70.31	57.50	64.26	56.14
10	50.76	53.03	69.45	58.43	63.48	54.37
11	48.37	51.92	67.86	63.46	59.75	55.49
12	51.33	53.71	67.79	56.54	62.17	59.77
13	47.91	53.47	67.09	56.72	63.13	55.98
14	48.76		66.59	61.50	63.09	53.87
15			67.10	57.88	63.23	53.39
16			68.07	56.76	63.27	53.81
17			65.78	52.87	63.86	55.67
18			66.47	52	61.15	52.77
19			64.98	50.20	59.80	51.98
20			63.24	52.84	61.52	54.66

(TABLE cont.)

21		62.48	54.65	61.77	55.94
22		64.80	53.05	63.76	53.41
23		64.65	54.61	63.96	51.85
24		66.79	52.92	63.79	53.93
25		64.38	56.88	63.93	56.10
26		63.47	54.54	65.01	52.39
27		64.57	51.90	65.80	53.63
28		64.26	54.84	64.71	56.92
29		65.47	53.20	65.23	59.92
30		66.08	54.96	65.80	56.47
31		64.25	50.31	62.35	56.35
32		63.99	51.62	63.50	54.16
33		64.97	55.20	63.34	59.13
34		65.15	53.41	61.81	60.6
35		64.22	54.24	61.80	58.31
36		65.24	53.57	61.28	57.96
37		64.46	53.12	61.95	56.77
38		62.87	55.84	61.28	52.05
39		63.21	49.08	60.34	52.74
40		64.03	49.11	61.84	54.85
41		62.74	47.96	63.05	55.23
42		63.21	46.06	59.64	57.22
43		59.99	47.21	61.53	59.41
44			48.82	60.70	50.87
45				58.84	51.58
46				58.86	49.50
47				58.65	48.22
48				60.19	53.61
49				59.94	48.65
50				60.51	51.65

(TABLE cont.)

51			58.95	55.86
52			56.86	51.08
53			55.25	48.45

Table 12. Percentage Decrease in Strength for Different Speeds of Dynamic Strength Testing(lbs)

Routine	Start Strength	End Strength	Total % Decrease in Strength	No. of cycles	Generalized Equation
1"/sec Pull	57.79	48.76	15.62	14	y=-0.7918x+59.092
1"/sec Push	58.3	53.47	8.28	13	y=-0.33x+57.07
5"/sec Pull	64.89	59.99	13.71	43	y=-0.1307x+68.04
5"/sec Push	59.95	48.82	18.56	44	y=-0.257x+60.541
10"/sec Pull	60.57	55.25	8.70	53	y=-0.874x+64.491
10"/sec Push	53.89	48.45	10.09	53	y=-0.05x+55.904

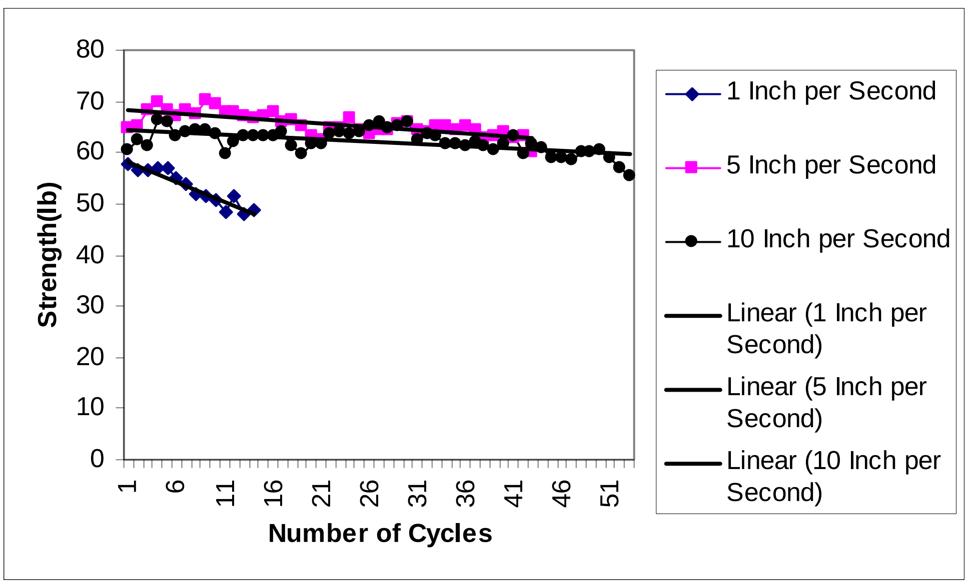

Figure 15. Average Pull Strength versus Number of Cycles of Subjects for 1, 5 and 10 Inch per Second Tests

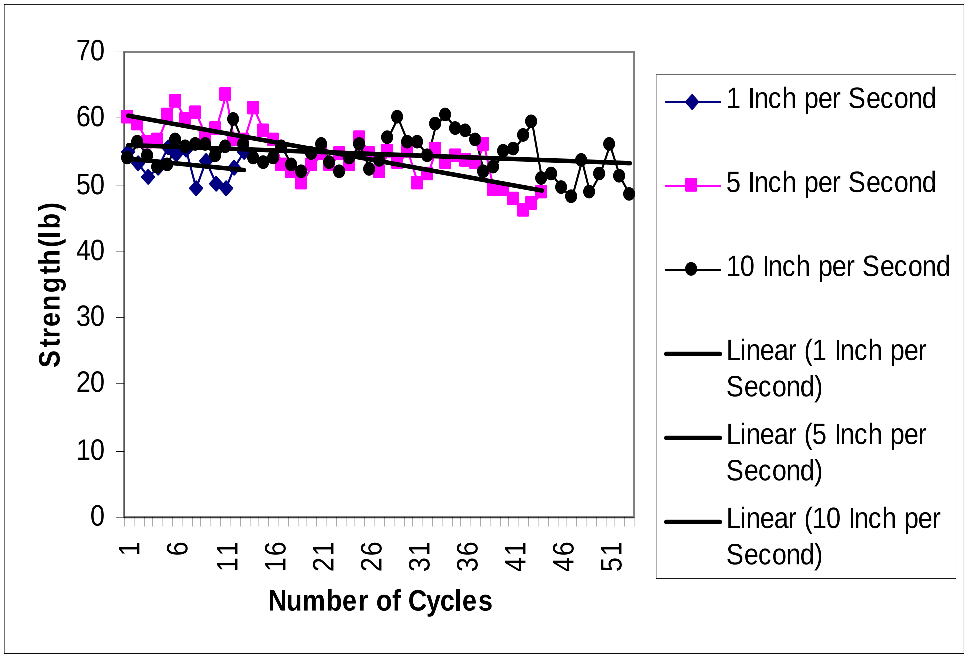

Figure 16. Average Push Strength versus Number of Cycles of Subjects for 1, 5 and 10 Inch per Second Tests

5.3 Analysis of EMG data of Part-I and Part-II

5.3.1 EMG Analysis of Part -I

EMG data was collected from the bicep muscle of all the participants in part-I of the study. The collected EMG readings from the subjects were analyzed using the median frequency.

A curve was fit to the median frequency values to see the fatigue in the muscles. As seen in Figures 17 and 18, there is a decrease in the frequency from the start to the end of the experiment and the rate of the decrease of frequency is different for each routine, indicating that the rate at which the fatigue occurs during each of the different experimental conditions varies. The average median frequency values of all the subjects for static and dynamic strength are as shown in the Figures 17 and 18, respectively.

The slopes were calculated for the trends which showed the rate of occurrence of fatigue. The frequency decrease is the highest rate for static six repetitions per minute where it decreased from 104.39Hz to 80.77Hz, followed by static three repetitions per minute where the frequency decreased from 111.33Hz to 100.77Hz and one repetition per minute where the frequency decreased from 101.69Hz to 96.97Hz, showing that the occurrence of fatigue is the highest during the static six repetitions per minute session.

This is in agreement with change in strength where the highest change occurred during static six repetitions per minute routine, where it decreased from 64.36lb to 48.72lb or decrease of 43%, followed by three repetitions per minute routine where it decreased from 63.5lb to 40.74lb, a decrease of 35.84%, and lastly during one repetition per minute where it decreased from 64.18lb to 53.78lb, a decrease of 16.2% (Table 10).

For dynamic strength also the rate of frequency decrease is the highest for dynamic six repetitions per minute where it decreased from 115.18Hz to 106.09Hz, followed by three repetitions per minute where it decreased from 74.80Hz to 72.30Hz and lastly for one repetition per minute where the frequency decreased from 72.38Hz to 71.39Hz.

This is in agreement with the change in strength where the highest change occurred during dynamic six repetitions per minute from 49.84lb to 37.7lb or 24.35%, followed by three repetitions per minute where it decreased from 52.2lb to 40.86lb, a decrease of 21.72%, and lastly during one repetition per minute where it decreased from 54.74lb to 51.92lb, a decrease of 5.15% (Table 10).

The rate of occurrence of fatigue is the highest during static six repetitions per minute routine and the least during dynamic one repetition per minute and the rate of fatigue occurrence during static strength testing is greater than during dynamic strength testing for all the three number of repetitions.

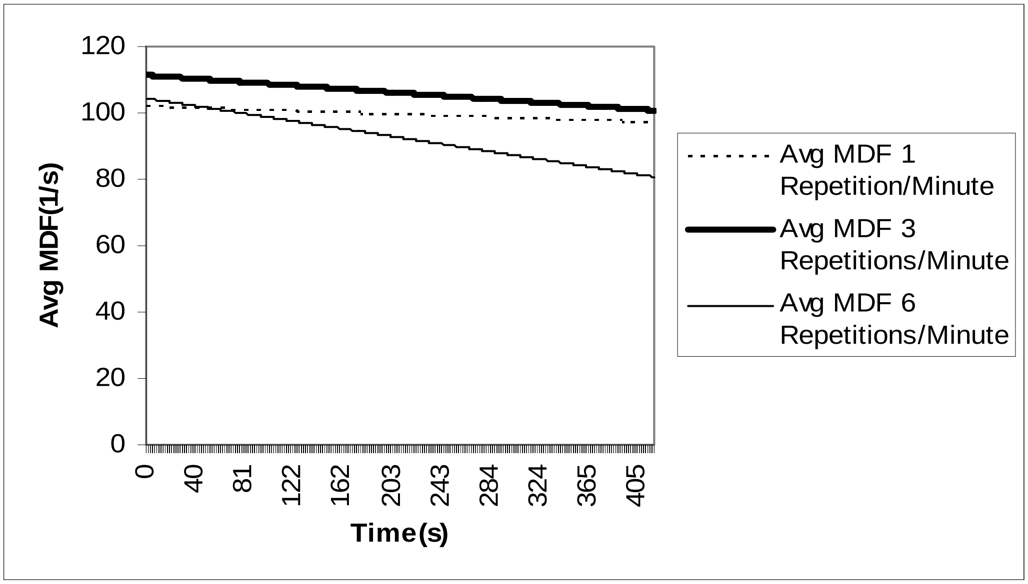

Figure 17. Average MDF versus Time for Static Strength

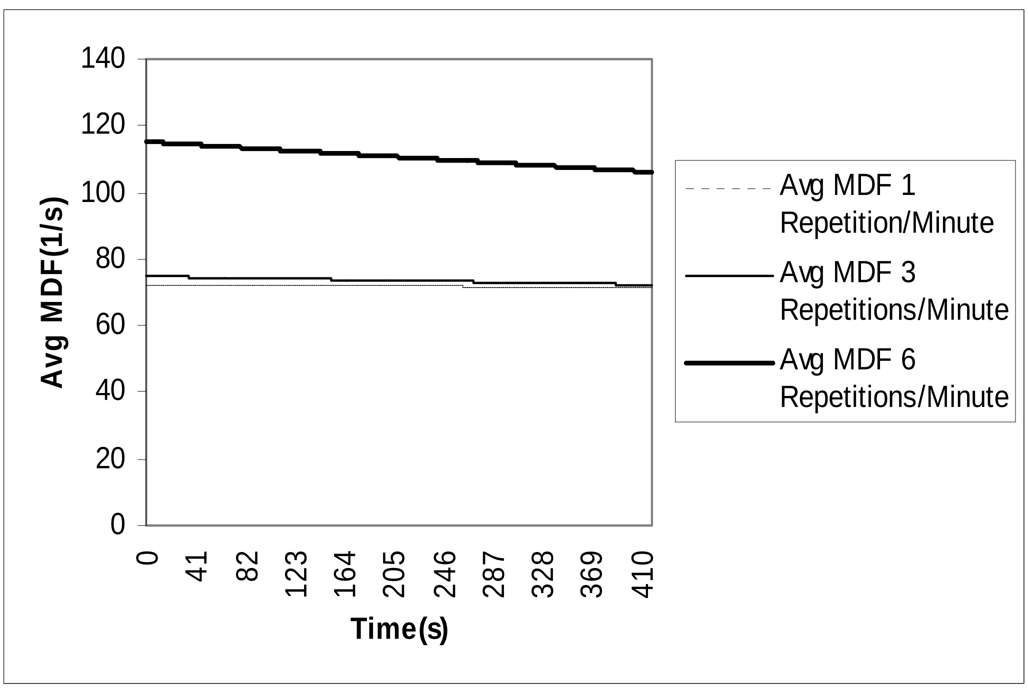

Figure 18. Average MDF versus Time for Dynamic Strength

5.3.2 EMG Analysis of Part -II

EMG data was collected from the triceps muscle of all the participants. The average MDF values of the triceps muscle were plotted for all subjects for one inch per second, five inch per second and ten inch per second dynamic strength testing routines.

As shown in Figure 19, during five inch per second strength testing routine the average median frequency of the subjects decreased from 73.91Hz to 64.02Hz, during one inch per second it decreased from 70.71Hz to 69.12Hz and during ten inch per second strength testing routine it decreased from 68.51Hz to 62.87Hz. This shows that the muscular fatigue occurred at the highest rate during the five inch per second speed and the least was during one inch per second. This is in agreement with change in strength where the highest change occurred during the five inch per second speed from 59.95lb to 48.82lb or 18.56% (Table 12). The least decrease in strength was during the one inch per second speed when the strength decreased from 58.3lb to 53.47lb, a decrease of 8.28%.

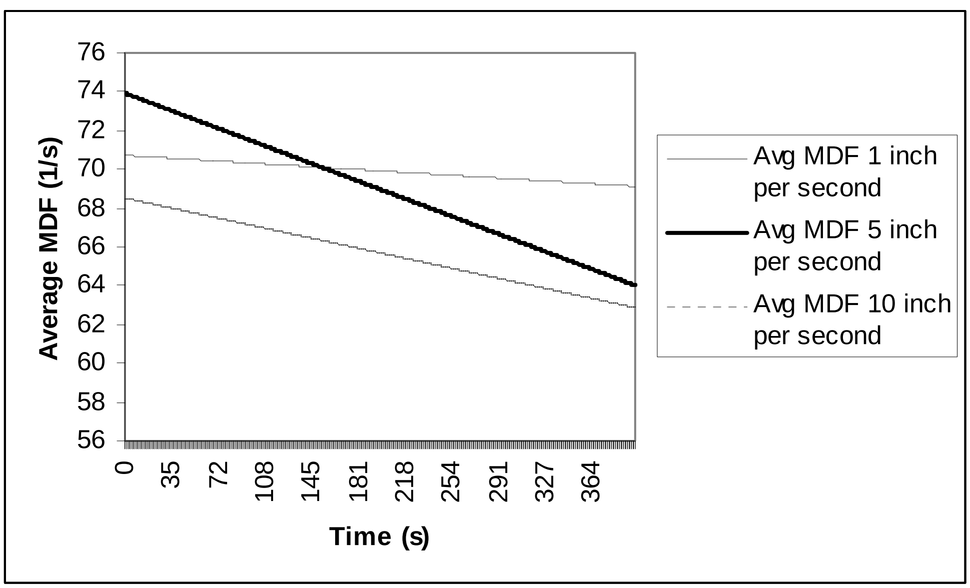

Figure 19. Average MDF versus Time for 1, 5 and 10 Inch per Second

5.4 Statistical Analysis of Data of Part-I and Part-II

The results of the paired T-test of the strength data of part I and II are presented in this section.

5.4.1 Statistical Analysis of Static Strength Data of Part-I

- **Static One Repetition per Minute**

As seen in the Table 13, for static one repetition per minute, at 95% confidence interval the mean difference is 10.4 and the p value is 0.002. This indicates that there is a significant difference in strength values at the start and at the end of the experiment session.

- **Static Three Repetitions per Minute**

The difference in means for static three repetitions per minute is 22.44 and the p value is 0.001 ($p<0.05$). This p value suggests that there is a significant difference in strength values at the start and at the end of the experiment session.

- **Static Six Repetitions per Minute**

As seen in the Table 13, for static one repetition per minute, at 95% confidence interval the mean difference is 31.36 and the p value is 0.000. This indicates that there is a significant difference in strength values at the start and at the end of the experiment session.

5.4.2 Statistical Analysis of Dynamic Strength Data of Part-I

- **Dynamic One Repetition per Minute**

The difference in means during dynamic one repetition per minute is 1.58. The p value is 0.421 (>0.05), which suggests that there is no significant difference between the strength at the start of the experiment and the strength at the experiment.

- **Dynamic Three Repetitions per Minute**

As seen in the Table 14, for dynamic three repetitions per minute, at 95% confidence interval the mean difference is 10.40 and the p value is 0.002. This value suggests that there is only a possibility of 0.2% that the strength values at the start of the experiment and at the end of the experiment are the same. This indicates that there is a significant difference in strength values at the start and at the end of the experiment session.

- **Dynamic Six Repetitions per Minute**

The difference in means for dynamic six repetitions per minute is 12.14 and the p value is 0.004 ($p<0.05$). This value suggests that there is only a possibility of 0.4% that the strength values at the start of the experiment and at the end of the experiment are the same. This p value suggests that there is a significant difference in strength values at the start and at the end of the experiment session.

Table 13. Statistical Data of Static Strength

No. of Repetitions per Minute	N	Mean		Standard Deviation		Confidence Interval		T	P
		Initial	Final	Initial	Final	5%	95%		
1	**5**	64.18	53.78	9.59	7.05	6.48	14.31	7.37	0.002
3	**5**	63.5	41.06	12.36	6.96	15.49	29.38	8.98	0.001
6	**5**	64.36	33	11.15	7.56	26.46	36.25	17.79	0.000

Table 14. Statistical Data of Dynamic Strength

No. of Repetitions per Minute	N	Mean		Standard Deviation		Confidence Interval		T	P
		Initial	Final	Initial	Final	5%	95%		
1	**5**	54.74	53.16	10.56	7.44	-3.31	6.47	0.90	0.42
3	**5**	52.20	41.80	8.60	6.82	6.94	13.85	8.36	0.001
6	**5**	49.84	37.70	11.40	8.32	6.45	17.82	5.93	0.004

5.5 Statistical Analysis of Data of part-II

5.5.1 Statistical Analysis of Pull Strength Data of Part-II

- **One Inch per Second Pull Strength**

The difference in means between the strength during this routine is 9.01 and the p value is 0.022 (<0.05) which suggests that there is a significant difference in strength values at the start and at the end of the experiment.

- **Five Inch per Second Pull Strength**

As seen in the Table 15, for pull strength during five inch per second speed, at 95% confidence interval the mean difference is 4.88 and the p value is 0.584 (>0.05). This value suggests that there is no significant difference in strength at the start of the experiment and at the end of the experiment.

- **Ten Inch per Second Pull Strength**

The difference in means between the strength during this routine is 5.32 and the p value is 0.306 (>0.05) which suggests that there is no significant difference in strength values at the start and at the end of the experiment.

Table 15. Statistical Data of Pull Strength

Speed (inch/sec)	N	Mean		Standard Deviation		Confidence Interval		T	P
		Initial	Final	Initial	Final	5%	95%		
1	**9**	57.78	48.76	10.65	7.51	1.67	16.35	2.83	0.02
5	**10**	64.89	60.00	21.41	17.39	-14.54	24.31	0.57	0.58
10	**10**	60.57	55.25	24.94	17.50	-12.43	17.07	1.09	0.30

5.5.2 Statistical Analysis of Push Strength Data of Part-II

- **One Inch per Second Push Strength**

The difference in means between the strength during this routine is 4.83 and the p value is 0.986 (>0.05) which suggests that there is no significant difference between strength values at the start and at the end of the experiment.

- **Five Inch per Second Push Strength**

As seen in the Table 16, for push strength during five inch per second speed, at 95% confidence interval the mean difference is 11.14 and the p value is 0.086 (>0.05). This value suggests that there is no significant difference in strength at the start of the experiment and at the end of the experiment.

- **Ten Inch per Second Push Strength**

The difference in means between the strength during this routine is 5.45 and the p value is 0.188 (>0.05) which suggests that there is no significant difference between strength values at the start and at the end of the experiment.

Table 16. Statistical Data of Push Strength

Speed (inch/sec)	N	Mean		Standard Deviation		Confidence Interval		T	P
		Initial	Final	Initial	Final	5%	95%		
1	**9**	58.3	53.47	13.91	14.62	-13.60	13.82	0.02	0.986
5	**10**	59.95	48.81	20.21	17.54	-1.97	24.18	1.93	0.086
10	**10**	53.91	48.45	19.04	18.93	-3.21	14.13	1.42	0.188

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

The study was divided into two parts; the objective of part I of the study was to determine the rate of decrease in static and dynamic strength with repetitions, and the objective of part II was to analyze the data collected using a Multipurpose Multiaxial Isokinetic Dynamometer to determine the trend and rate of decrease in dynamic strength with different speeds. Results of previous studies show that the strength decreased linearly with prolonged exertions. A study by Caldwell (1964) showed that the percentage maximum strength decreased linearly with prolonged exertion. Brown et al. (1986) in his study also found that the strength exerted continuously decreased linearly. The previous studies explored the change in strength with prolonged exertions and concluded that strength decreased linearly. The results of the present study also showed a linear decrease in strength but the effect of repetitions was taken into account. The results of Part I and II of the study showed that strength decreased linearly with repetitions and the rate of decrease of strength depended on the number of repetitions per minute.

6.1 Conclusions of Part-I

Five male students were used as subjects in part I of the study. Anthropometric measurements (height and weight) of all five subjects were recorded. During the experiment each subject performed six routines, three static and three dynamic. The results showed that both static and dynamic strengths decreased in a linear fashion. Though both static and dynamic strengths decreased in a linear fashion, the observed rate of decrease of static strength was higher for all three conditions than dynamic strength. The highest percentage decrease in strength was for static strength at six repetitions per minute, where the strength decreased from 64.36 lb to 33 lb or a decrease of 48 percent.

The least percentage decrease in strength was for dynamic one repetition per minute where the strength decreased from 54.74 lb to 51.92 lb which accounts to a decrease of 5.15 percent.

EMG analysis concluded that the occurrence of fatigue was the highest during the six repetitions per minute as compared to the three and one repetition per minute tests. Median frequency analysis shows that the shift in frequency was the highest during the six repetitions per minute test than three and one repetition per minute tests. This substantiates the fact that the observed rate of decrease in strength was higher during the six repetitions per minute in comparison to three and one repetition per minute. Again the occurrence of fatigue was higher during static exertion rather than dynamic exertion, which accounts for the fact that the total decrease in strength was higher during static exertions than the dynamic exertion.

6.2 Conclusions of Part-II

Ten male subjects participated in this study. The subjects were employee volunteers of NASA-Johnson Space Centre, Houston, Texas. The analysis of the data collected using the Multipurpose Multiaxial Isokinetic Dynamometer shows that the strength decreased linearly for different speeds and the observed rate of decrease in strength was the highest during the one inch per second speed and the least was during the ten inch per second test. During one inch per second the strength decreased from 57.79 lb to 48.76 lb which accounts for a decrease of 15.62%. All subjects were able to exert the maximum strength during the five inch per second speed, though the rate of decrease in strength of five inch per seconds was greater than the ten inch per second speed. Median frequency analysis of the EMG shows that the rate of occurrence of fatigue was the highest during the one inch per second speed and the least during the ten inch per second which supports the fact that the rate of decrease of strength was the highest during the one inch per second and the least during the ten inch per second.

The results of both parts of the study showed that the strength decreases in a linear fashion for both static and dynamic work, with the rate of decrease depending on the rest periods provided and the speed during the dynamic exertions. Under the same conditions, static strength decreasing more than dynamic strength supports the already existing fact that dynamic work is less fatiguing than static work. Another important conclusion derived from this study is that the optimum speed of dynamic exertions may be five inch per second as the subjects were able to exert their maximum dynamic strength during this speed. This result may be used to design any work conditions which require the worker to exert maximum strength.

6.3 Comparison of Strength Data of This Study with the Previous Studies

The results of this study show that the average static arm lift strength exerted by the participants were 64.18 lb, 63.5 lb and 64.36 lb during one, three and six repetitions per minute, respectively. The average dynamic strength exerted were 54.74 lb, 52.2 lb and 49.84 lb during one, three and six repetitions per minute, respectively. It is observed that the dynamic strength during one repetition per minute was 85.29% of static strength, dynamic strength during three repetitions per minute was 82.2% of static strength and dynamic strength during six repetitions per minute was 77.4% of static strength. A comparison of dynamic strength as a percentage of static strength from various studies is shown in Table 17. A study by Aghazadeh et al. (1985) shows that dynamic arm strength during floor to shoulder was 69.7% of static arm strength whereas dynamic arm strength during knuckle to shoulder height was 30.6% of static arm strength. The results of a study by Kumar (1991) show that dynamic arm strength (Knuckle to shoulder) at 50% of reach position was 52.7% of static strength, at 75% of reach position was 76.2% of static strength and the dynamic strength at 100% of reach position was 88% of static arm strength.

Table 17: Comparison of Dynamic Strength as a Percentage of Static Strength from Various Studies

Study	Experimental Condition	Static Strength	Dynamic Strength	Dynamic Strength as a Percentage of Static Strength
Present Study	**One Repetition per Minute**	285.47 (N)	243.48 (N)	85.2
	Three Repetitions per Minute	282.44 (N)	232.18 (N)	82.2
	Six Repetitions per Minute	286.27 (N)	221.68(N)	77.4
Aghazadeh et al. (1985)	**Arm Strength**	431.6 (N)	301.1 (N) Floor to Shoulder	69.7
			132.3 (N) Knuckle to Shoulder	30.6
Kumar (1991)	**Arm Strength 0.5Reach Position**	590 (N)	311 (N)	52.7
	Arm Strength 0.75Reach Position	295 (N)	225 (N)	76.2
	Arm Strength 1Reach Position	184 (N)	162 (N)	88

6.4 Practical Applications

The results of the study which suggest that static and dynamic strengths decrease linearly with repetitions may be used in the design of tools, work and workplace. It may also be used in screening of workers for different jobs and assigning rest cycles.

Design of tools, work and work place is based on the maximum strength value of the 95th percentile of the population. Maximum strength value method would result in the design of the tools, work or workplace requiring the maximum strength of the worker to be employed. The decrease in strength with repetitions is not taken into account.

If the time of operation of the tool in each shift is known, the tools should be designed such that the strength required to operate them is not the maximum strength, but the strength of the worker at the end of the time period of the operation of the tool. This value of strength may be estimated by substituting the maximum strength value of the worker in the linear equation. Use of this method in tool design would reduce the load on the workers and hence reduce injuries. The same principle may also be followed in the design of work and workplace.

The results of the study may also be used to design the rest cycles for the workers. If the strength required to operate a machine or a tool is known, then the time taken for the strength of a worker who operates that machine or tool to reduce below the required operating strength value can be calculated using the linear equation (Table 10). Rest cycles may be assigned to the workers at the end of that particular time period so that they do not operate the machine or tool beyond that time and hence can avoid injuries.

6.5 Recommendations for Future Work

- Female subjects may be used in future studies.
- The effect of rest periods on dynamic strength at different speeds may be studied.

  Part-II of this study may be repeated with fixed rest periods between each repetition at different speeds to determine the effect of rest periods on dynamic strength at different speeds.
- The study can be extended to include other numbers of repetitions per minute to observe the change in strength.
- A study can be done to determine recovery rate of the muscles with different speeds or different number of repetitions. This would help to determine the optimum speed for dynamic work or the optimum number of repetitions.
- Similar studies can be performed to determine the pattern of change in strength in older people.

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APPENDIX-A

ANTHROPOMETRIC DATA OF SUBJECTS

Anthropometric data of subjects in Part I

Subject Number	Gender	Age	Height (Inches)	Weight(Lb)
1	M	22	67.7	160
2	M	22	68.1	156
3	M	24	70	179
4	M	20	68.8	180
5	M	21	69.6	174

Anthropometric data of subjects in Part II

Subject No.	Gender	Age (Years)	Height(Inches)	Weight(lb)
1	M	51	72	190
2	M	26	--	--
3	F	24	66	150
4	F	32	64	155
5	M	24	74	230
6	M	25	70	195
7	M	34	71	160
8	M	46	70	135
9	M	35	66	150
10	M	48	72	230
11	M	47	68	155
12	M	41	68	190

APPENDIX-B

STATIC AND DYNAMIC STRENGTH DATA OF SUBJECTS DURING DIFFERENT ROUTINES

Strength Data of Subjects from Part-1 of the Study

Subject-1 (1 repetition per minute strength testing cycle)

Time (Sec)	Static Strength(lb)	Dynamic Strength(lb)
0	54.3	42.9
60	51.3	43.2
120	49.4	43.9
180	51.6	42.7
240	50.6	43.3
300	49.7	42.9
360	48.2	42
420	46.1	41.7

Subject-1 (3 Repetitions per Minute strength testing cycle)

Time (Sec)	Static Strength(lb)	Dynamic Strength(lb)
0	47.9	44.7
20	45.1	42.7
40	42	45
60	40.3	42.6
80	52	44.8
100	46	36.2
120	51.7	33.2
140	41	34.5
160	49.3	39.4
180	45.9	41.9
200	46.2	39.2
220	37.6	42.2
240	41.4	34.2
260	34.9	40.8
280	45.3	47.4
300	34.1	35.9
320	35.1	41.3
340	41	40.8
360	33.9	35.4
380	34.1	34.4
400	33.6	34.1
420	32.1	33.9

Subject-1 (Six Repetitions per Minute strength testing cycle)

Time (Sec)	Static Strength(lb)	Dynamic Strength(lb)
0	55.2	36.1
10	51.3	37.9
20	46.5	43.9
30	53.1	40.8
40	53.5	43.2
50	50.6	34.3
60	28.1	39.8
70	29.7	43.7
80	44.3	43.2
90	31.9	42.5
100	32.4	43.4
110	52.4	38.2
120	35.4	41.4
130	45.1	39.4
140	45.9	38.6
150	29.4	32.8
160	42.9	40.6
170	26.4	34.1
180	42.1	36.5
190	28.5	25.8
200	33.7	36.7
210	27.9	29.4
220	34.9	30.4
230	26	38.6
240	40.7	37.9
250	27.2	38.2
260	26.1	27.6

270	26.9	38
280	28.3	27.6
290	25.9	31.9
300	19.2	27.9
310	26.3	27.9
320	26.7	27.9
330	26.1	29.7
340	27.4	28.6
350	27.9	27.7
360	25.9	28.1
370	28.2	28.3
380	18.4	27.4
390	26.3	27.5
400	25.9	28.1
410	25.2	27.4
420	25.4	27

Subject-2 (1 repetition per minute strength testing cycle)

Time (Sec)	Static Strength(lb)	Dynamic Strength(lb)
0	65	53.4
60	53.4	51.8
120	57.4	52.3
180	55.2	52.4
240	52.9	50.6
300	50.2	51.2
360	53.8	50.8
420	53.2	50.6

Subject-2 (Three Repetitions per Minute strength testing cycle)

Time (Sec)	Static Strength(lb)	Dynamic Strength(lb)
0	64.7	51.3
20	60.7	54.7
40	63.9	52.4
60	57.8	53.2
80	55.8	53.6
100	62.8	51.4
120	62.7	50
140	57.4	52.9
160	52.6	50.1
180	52.4	50.3
200	52.3	48.7
220	50.1	49.9
240	52	51.4
260	52.1	46.9
280	54.7	49.3
300	51.2	50.3
320	48.6	53.2
340	52.3	52.6
360	48.9	43.9
380	45.4	42.4
400	43.7	42.8
420	43.4	42.6

Subject-2 (Six Repetitions per Minute strength testing cycle)

Time (Sec)	Static Strength(lb)	Dynamic Strength(lb)
0	67.5	48.6
10	63.1	45.2
20	66.8	52.9
30	67.2	49.4
40	64.3	43.1
50	59.2	52.3
60	53.2	49.6
70	58.9	47.8
80	57.6	52.1
90	64.3	48.2
100	64.5	45.8
110	52.8	46.5
120	55.7	47.4

130	61.4	39.9
140	52.1	46.8
150	53.5	52.9
160	67.8	46.8
170	57.6	42.5
180	48.6	41.9
190	44.3	42.6
200	50.6	53.1
210	41.4	38.6
220	39.2	45.4
230	40.9	38.3
240	67.9	41.4
250	51.8	44.6
260	39.5	47.7
270	37.6	40.4
280	36.8	49.6
290	57.2	36.9
300	37.3	40.5
310	36.1	33.2
320	35.3	39.1
330	35.8	41.1
340	35.1	48.2
350	36.3	37.3
360	35.4	42.8
370	33.6	40.6
380	29.6	38.1
390	35.3	36.9
400	37.1	39.6
410	34.9	37.4
420	33.8	37.2

Subject-3 (1 Repetition per minute strength testing cycle)

Time (Sec)	Static Strength(lb)	Dynamic Strength(lb)
0	66.8	56.2
60	64.3	55.1
120	59.9	56.3
180	56.2	54.9
240	64.1	53.6
300	56.4	53.4
360	54.3	53.2
420	54.1	53.6

Subject-3 (3 Repetitions per minute strength testing cycle)

Time (Sec)	Static Strength(lb)	Dynamic Strength(lb)
0	64.3	54.1
20	53.6	53.7
40	69.9	51.2
60	56.5	50.8
80	69.3	49.6
100	66.2	50.4
120	56.9	50.3
140	63.9	48.5
160	59.4	51.9
180	50.1	46.9
200	61.7	46.6
220	46.4	53.9
240	47.8	49.2
260	47.2	53.1
280	59.1	52.9
300	53.1	45.1
320	44.3	50.6
340	46.9	49.4
360	41.1	50.2
380	42.3	42.9
400	41.9	45.5

Subject-3 (6 Repetitions per minute strength testing cycle)

Time (Sec)	Static Strength(lb)	Dynamic Strength(lb)
0	61.7	47.1
10	58.2	58.1
20	67.6	41.3
30	60.5	57.6
40	67.9	50.4
50	66.8	57.1
60	61.3	47.7
70	64.2	49.3
80	47.6	53.5
90	60.6	47.9
100	57.8	46.8
110	56.4	47.3
120	61.5	45.8
130	67.8	46.5

140	58.7	45.3
150	67.7	49.2
160	66.5	56.4
170	60.4	43.4
180	71.8	44.8
190	52.3	52.8
200	67.2	49.6
210	72.4	44.1
220	62.4	49.6
230	58.4	53.6
240	60.5	49.1
250	48.4	56.8
260	54.3	46.2
270	60.3	43.8
280	45.1	42.6
290	52.1	43.1
300	54.6	44.3
310	44.5	42.1
320	58.6	43.9
330	37.1	41.7
340	42.4	41.8
350	33.3	42.4
360	34.2	42.2
370	40.8	43.1
380	38.3	41.1
390	33.6	40.9
400	32.4	43.5
410	33.9	40.6
420	32.6	40.3

Subject-4 (1 repetition per minute strength testing cycle)

Time (Sec)	Static Strength(lb)	Dynamic Strength(lb)
0	78.4	71.4
60	74.3	70.2
120	69.4	71.3
180	75.8	69.3
240	68.7	67.1
300	70.5	67
360	65.6	65.3
420	65.1	65.8

Subject-4 (3 Repetitions per minute strength testing cycle)

Time (Sec)	Static Strength(lb)	Dynamic Strength(lb)
0	82	65.8
20	78.4	68.7
40	76.4	54.5
60	75.4	63.2
80	75.8	68.9
100	72.6	65.8
120	75.9	55.6
140	61.4	66.5
160	71.4	56.6
180	73.1	66.1
200	59.6	65.4
220	72.6	56.4
240	70.9	54.1
260	51.9	54.7
280	55.3	59.5
300	54.2	51.6
320	53.6	56.7
340	54.6	52.4
360	52.1	50.3
380	51.3	54.4
400	50.2	54.6
420	50.7	50.7

Subject-4 (6 Repetitions per minute strength testing cycle)

Time (Sec)	Static Strength(lb)	Dynamic Strength(lb)
0	82.1	67.8
10	86.5	70.9
20	61.2	68.6
30	65.5	63.4
40	79.6	49.9
50	83.4	56.7
60	59.5	61.5
70	69.4	56.1
80	87.2	58.7
90	70.3	58.5
100	86.9	51.4
110	76.2	63.6
120	86.1	60.8

(TABLE Cont.)

130	66.4	56.3
140	67.8	49.6
150	63.4	50.3
160	62.9	51.8
170	61.3	60.4
180	59.1	58.4
190	59.6	50.4
200	54.4	53.4
210	72.8	49.2
220	62.8	50.6
230	62.7	50.5
240	48.9	63.9
250	46.5	49.7
260	54.5	50.6
270	48.6	51.2
280	57.4	58.5
290	48.4	56.2
300	45.2	49.8
310	45.7	53.8
320	48.6	56.5
330	45.9	53.5
340	46.2	53.1
350	48.7	50
360	46.8	49.7
370	45.3	46.3
380	44.7	50.4
390	44.9	49.9
400	43.6	49.6
410	44.8	49.4
420	45.1	49.7

Subject-5 (1 Repetition per minute strength testing cycle)

Time (Sec)	Static Strength(lb)	Dynamic Strength(lb)
0	56.4	49.8
60	57.3	48.1
120	56.2	49
180	52.9	48.3
240	56.9	48.6
300	54.3	48.2
360	51.6	47.4
420	50.4	47.9

Subject-5 (3 Repetitions per minute strength testing cycle)

Time (Sec)	Static Strength(lb)	Dynamic Strength(lb)
0	58.6	45.1
20	48.7	48.3
40	58	42
60	57.3	48.1
80	53.1	46.3
100	46.3	47.9
120	44.6	45.1
140	45.3	44.8
160	47.9	41.4
180	45.9	39.5
200	48	38.2
220	38.2	41.4
240	44.1	39.2
260	47.6	41.2
280	44.6	38.3
300	38.1	37.2
320	38.6	40.6
340	36.1	38.1
360	36.9	36.3
380	38.2	40.5
400	47.9	36.9
420	37.2	36.3

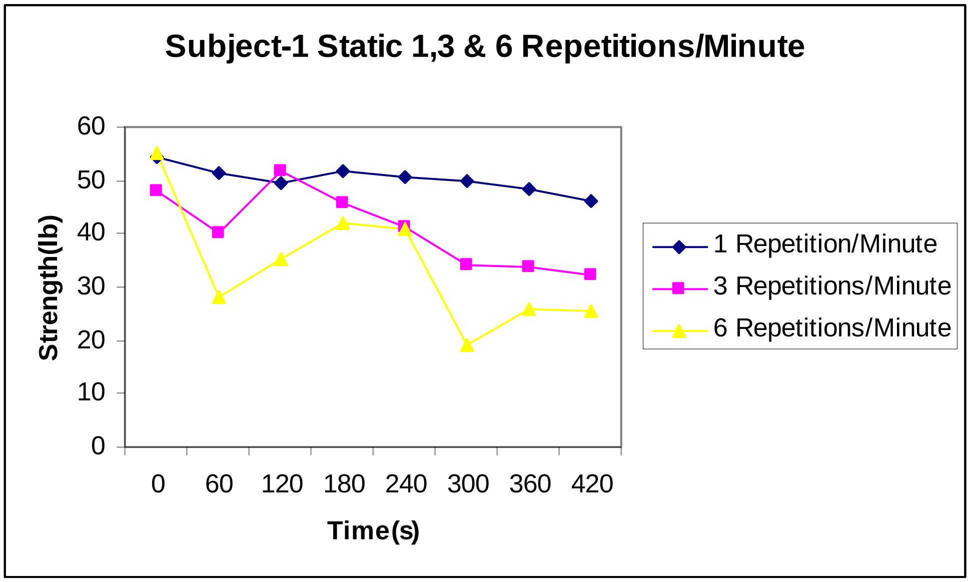
Subject-5 (6 Repetitions per minute strength testing cycle)

Time (Sec)	Static Strength(lb)	Dynamic Strength(lb)
0	55.3	49.6
10	47.6	47.4
20	56.9	36.4
30	45.4	40.3
40	45.8	46.5
50	52.6	36.5
60	55.9	44.3
70	55.6	35.3
80	55.4	41.6
90	52.1	38.4
100	44.2	36

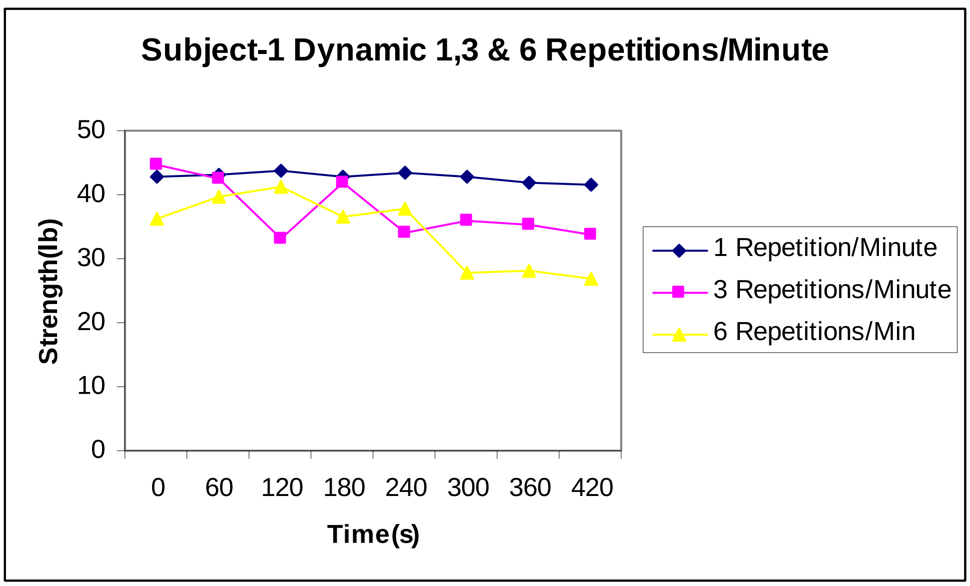
(TABLE Cont.)

110	51.9	40.1
120	44.6	44.5
130	35.1	36.1
140	53.8	39.2
150	42.6	35.9
160	42.3	41.1
170	45.3	37.6
180	40.1	37.1
190	43.7	39.4
200	45.9	36.1
210	36.3	39.5
220	31.6	42.9
230	32.7	38.6
240	32.9	38.3
250	35.6	36.4
260	31.1	36.8
270	30.4	39.6
280	31.4	36.1
290	30.1	35.5
300	31.8	35.1
310	28.4	34.9
320	33.4	35.2
330	30.2	35.6
340	44.6	34.9
350	25.1	35.1
360	27.9	35.3
370	22.6	34.5
380	27.1	34.1
390	26.9	34.3
400	27.4	33.9
410	29.4	33.8
420	28.1	34.3

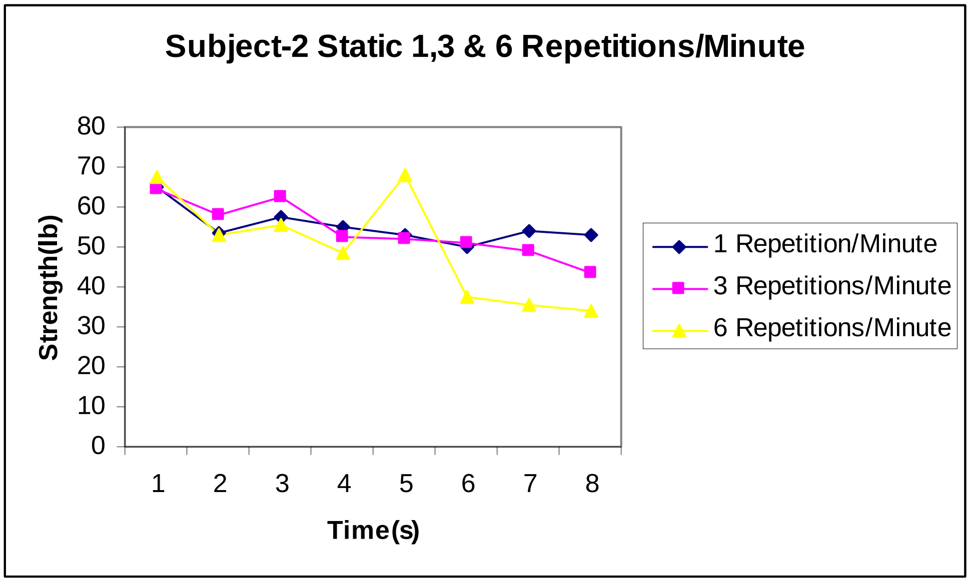
The Strength values at intervals of 60s were taken and plotted for one, three and six repetitions per minute for all the subjects.



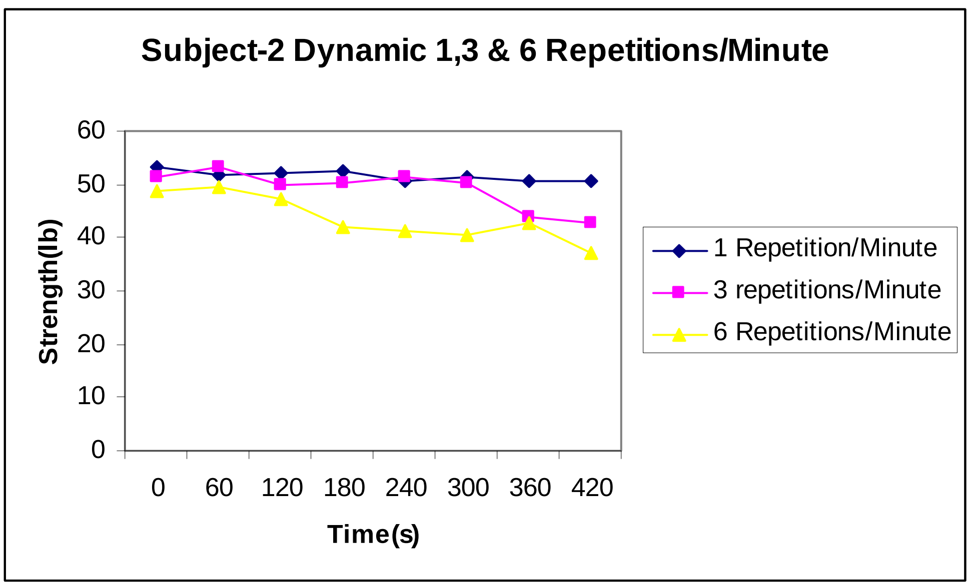
Subject-1 (Static Strength at 1, 3 and 6 repetitions per minute cycles)



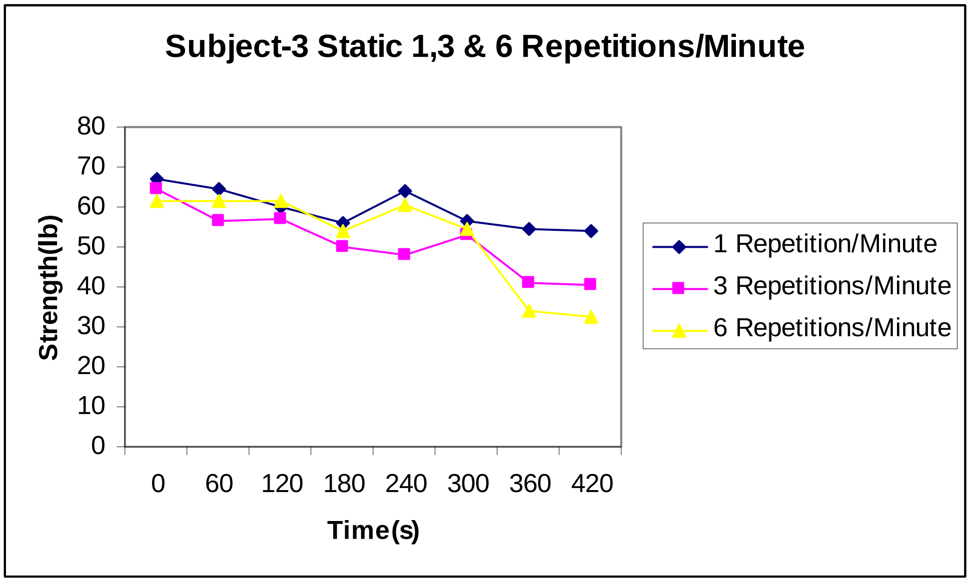
Subject-1 (Dynamic Strength at 1, 3 and 6 repetitions per minute cycles)



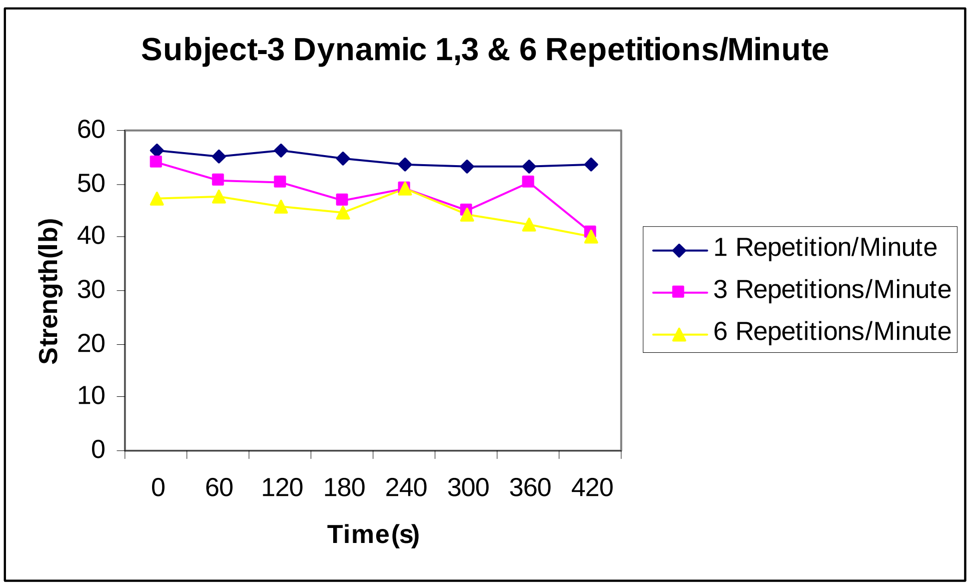
Subject-2 (Static Strength at 1, 3 and 6 repetitions per minute cycles)



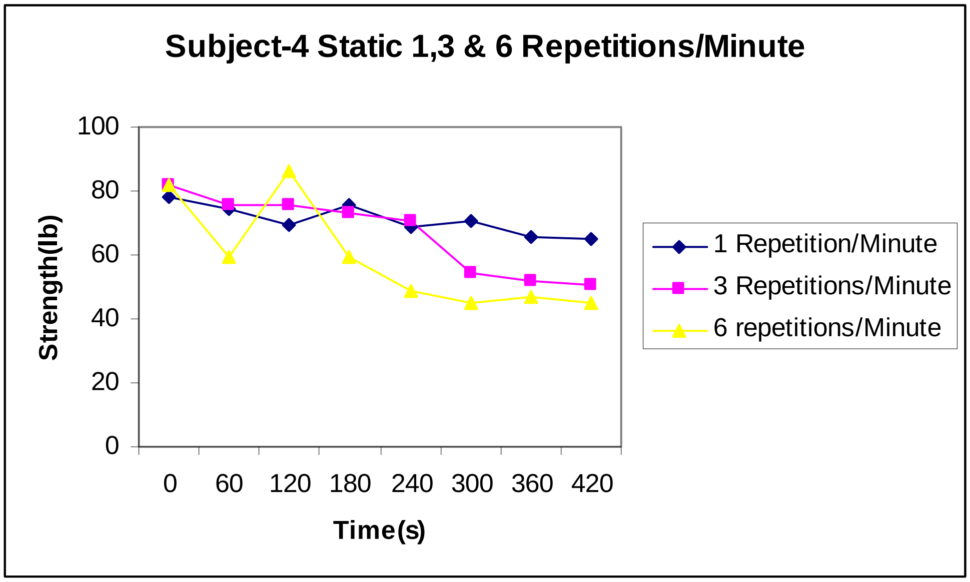
Subject-2 (Dynamic Strength at 1, 3 and 6 repetitions per minute cycles)



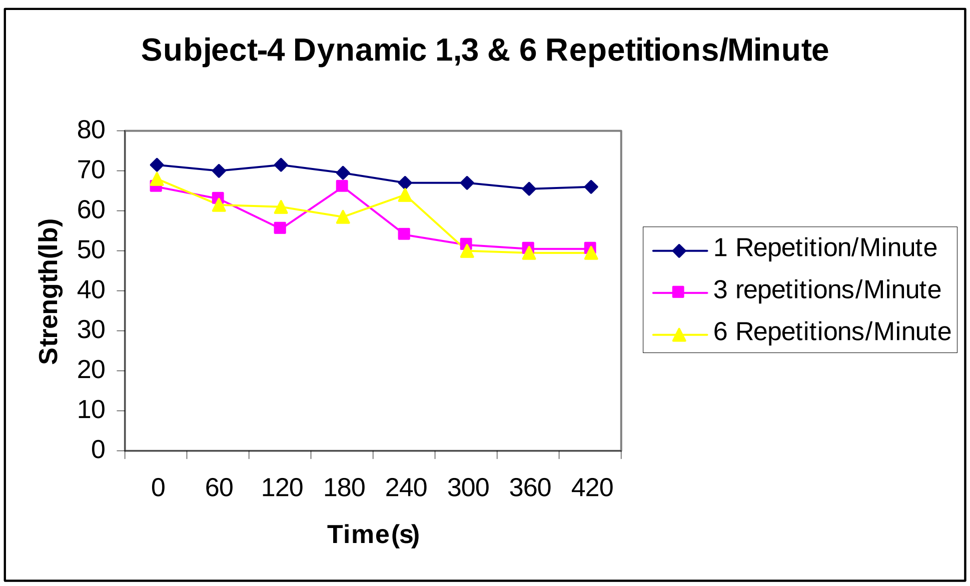
Subject-3 (Static Strength at 1, 3 and 6 repetitions per minute cycles)



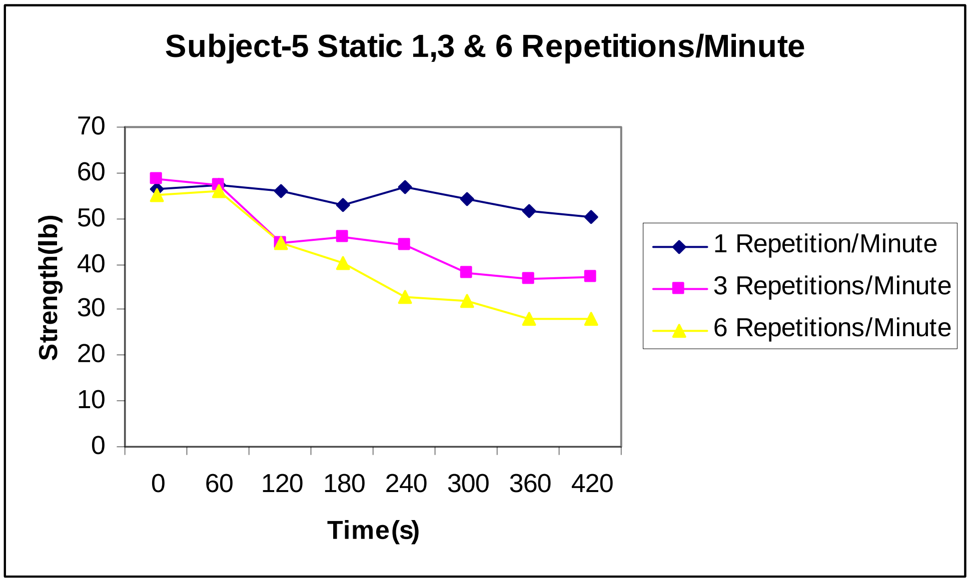
Subject-3 (Dynamic Strength at 1, 3 and 6 repetitions per minute cycles)



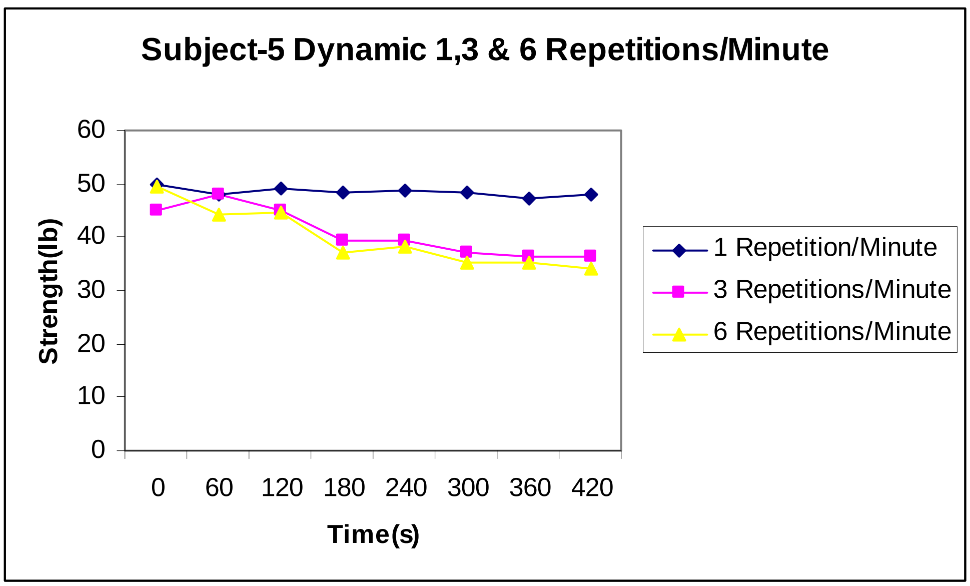
Subject-4 (Static Strength at 1, 3 and 6 repetitions per minute cycles)



Subject-4 (Dynamic Strength at 1, 3 and 6 repetitions per minute cycles)



Subject-5 (Static Strength at 1, 3 and 6 repetitions per minute cycles)



Subject-5 (Dynamic Strength at 1, 3 and 6 repetitions per minute cycles)

Strength Data of subjects from Part-2 of the Study

Subject-1

Pull & Push strengths during 1, 5 & 10 Inch/Sec Routines

1 Inch per Second		5 Inch per Second		10 Inch per Second	
Pull	**Push**	**Pull**	**Push**	**Pull**	**Push**
57.92	68.59	46.82	73.32	34.03	51.95
51.61	63.7833	55.11	74.88333	33.02333333	52.80333
41.43333333	54.95	48.87	65.39667	35.51666667	54.79667
42.93333333	54.3633	41.0833333	62.46667	31.61666667	56.64333
37.94	62.4067	64.1033333	64.12	33.77	53.39333
41.96	45.95	46.01	62.68667	34.41	53.35
40.38333333	57.1567	45.3533333	63.98	35.5	56.03
36.07666667	55.8	45.3233333	63.63333	37.58333333	56.58
35.91	61.52	48.8033333	58.94	37.01333333	52.46667
37.37333333	52.3233	46.3833333	58.80667	34.83	53.83333
40.83666667	51.6	43.53	56.85	37.26333333	58.42667
37.96333333	54.66	42.9933333	55.9	38.1	59.59667
41.90333333	54.6433	44.17	60.53	37.92666667	59.09
42.59333333		44.67	62.47	37.81666667	57.77
		49.9966667	60.17667	39.98333333	60.59667
		59.0633333	54.51	38.47666667	59.06333
		46.52	53.82	42.14333333	60.37333
		52.0733333	50.81333	33.43666667	61.85333
		55.86	49.52667	36.55666667	59.22667
		49.0366667	52.04333	34.12	61.55
		48.4633333	56.67333	35.84	56.20667
		54.5533333	53.21667	35.13333333	60.03333
		55.1333333	50.79333	38.33666667	53.38333
		55.6933333	55.49333	41.22	54.66333
		49.3833333	51.32	37.43333333	56.06
		47.09	50.47667	35.56333333	53.87667
		59.25	49.65333	39.13	57.3

		55.7466667	56.63333	35.67333333	54.56
		58.6266667	50.89667	32.37666667	57.13667
		63.76	47.48667	38.67333333	60.13333
		56.5966667	47.04667	39.23	60.06667
		55.2633333	52.51667	45.96	60.64667
		58.9	49.06333	44.10333333	55.51333
		60.5933333	46.53	47.44333333	55.99
		63.5433333	44.25333	43.55666667	50.09
		55.4566667	51.38667	40.76	55.25
		59.4566667	44.95667	46.16666667	51.91667
		50.1966667	48.73667	42.38666667	49.57
		51.66	46.71	42.13	47.31333
		58.7933333	42.46	45.56333333	52.34333
		47.7733333	45.44333	43.21	51.55667
		50.2366667	43.01	39.25333333	50.63
		49.8233333	43.80667	43.48666667	50.01667
			44.06333	43.98333333	48.76667
				40.92666667	50.31667
				47.36	48.26
				46.15333333	42.38667
				43.34333333	46.21333
				44.59666667	44.15667
				45.02666667	41.14
				49.89333333	45.81333
				42.14666667	42.20667
				41.53	49.06667

Subject-2

Pull & Push strengths during 1, 5 & 10 Inch/Sec Routines

1 Inch per Second		5 Inch per Second		10 Inch per Second	
Pull	**Push**	**Pull**	**Push**	**Pull**	**Push**
49.03666667	59.5233	53.3033333	55.59333	44.93333333	55.12667
52.74666667	52.59	57.02	50.86333	51.52	46.06667
59.08	49.9533	58.8633333	47.47333	52.65333333	39.96333
58.4	48.0767	57.0666667	43.24667	58.05333333	42.26667
61.79666667	44.57	53.6866667	45.53667	54.08	34.77
62.48666667	47.08	53.95	46.58667	55.83	37
61.14333333	48.2167	55.0933333	46.35333	60.16	38.95
54.19333333	51.6267	54.4833333	41.36333	58.90666667	37.76
40.96	53.2633	57.31	35.81	58.27666667	37.31
45.96	52.7233	55.6266667	44.93667	57.26666667	36.02333
38.19	49.5367	56.2166667	43.92	58.80666667	36.66333
44.22	50.9167	52.39	33.09	56.34666667	32.85667
39.49	51.8433	53.2366667	38.37	53.36333333	32.94333
53.73		52.8566667	40.99667	55.10333333	31.79
		56.9366667	36.01333	53.71666667	32.7
		55.4366667	38.52333	56.1	39.96333
		57.0933333	35.03667	56.69333333	41.15
		58.33	37.85	57.87	41.30333
		59.82	36.10333	54.08333333	40.27
		57.46	35.81	55.21666667	37.38667
		50.6966667	31.32333	60.78333333	35.63667
		52.6166667	33.35333	57.33	34.33333
		54.2266667	33.12	58.6	34.99667
		56.02	29.84667	59.09	38.36333
		53.51	39.59333	55.07333333	32.02
		56.8933333	37.53333	60.11666667	34.29333
		58.8766667	40.82333	57.88333333	29.61333
		59.6733333	37.84667	57.60333333	32.57333

(TABLE Cont.)

		63.2	36.24333	57.96	34.88333
		65.2733333	34.98333	65.3	34.10333
		63.66	35.18667	61.58333333	41.09
		63.32	36.30667	65.27666667	40.17
		62.3866667	33.74	66.02333333	36.7
		64.1966667	37.49	67.32666667	35.17
		62.6266667	39.73667	66.77333333	34.18333
		59.39	41.41667	67.51	35.63
		61.0166667	37.73333	65.48666667	33.06
		65.1066667	38.77333	64.63	34.17333
		61.71	37.15667	65.81666667	34.16667
		58.7833333	39.00667	63.49	32.07667
		56.6133333	30.86667	63.01	38.38333
		56.85	37.21667	63.37666667	42.85333
		49.6366667	35.86333	58.84333333	38.74333
			31.44	64.88	36.52
				63.43333333	33.94
				63.40333333	35.30667
				62.26666667	33.57667
				64.04	32.99667
				63.77333333	34.03667
				67.88	35.26333
				59.68666667	40.18333
				37.29	42.77
				40.71666667	38.95667

Subject-3

Pull & Push strengths during 1, 5 & 10 Inch/Sec Routines

1 Inch per Second		5 Inch per Second		10 Inch per Second	
Pull	**Push**	**Pull**	**Push**	**Pull**	**Push**
83.50666667	55.4133	111.9	91.2	81.02666667	62.68667
61.53666667	52.21	103.496667	89.58	89.95666667	58.68667
67.48	54.96	112.406667	88.72	75.41666667	65.62
65.48333333	55.37	118.2	82.46333	91.01333333	60.54
73.85	54.04	102.223333	80.31667	85.93333333	79.25333
63.89	55.3267	92.9633333	88.76667	85.22333333	77.48333
65.89666667	54.2467	103.67	81.31667	74.14	80.73333
55.62333333	50.4033	102.833333	95.27333	75.62	71.04333
52.00666667	63.2233	102.946667	90.42667	69.50666667	67.22667
59.99	57.9767	102.736667	75.07333	75.74	63.72
56.27666667	56.37	103.52	90.06667	63.92666667	83.85
62.38333333	54.7367	94.8	68.34667	70.45	81.21
54.68666667	55.3767	88.2066667	66.09	69.29	64.38667
61.80333333		92.37	72.98667	62.03	67.39667
		80.31	71.88	63.01	68.71333
		84.5933333	69.87333	58.35666667	58.81
		80.9633333	62.22	71.77666667	92.27
		94.0866667	58.52	71.59666667	79.82
		77.5466667	53.93	64.37333333	62.72
		72.9566667	55.03667	65.80666667	64.14
		67.6733333	59.53667	73.02	85.91667
		75.0066667	63	66.31666667	78.82333
		80.1633333	67.32667	75.93	73.95333
		89.28	66.73	82.08333333	75.63333
		72.1566667	55.18333	66.75	93.62333
		65.5833333	59.22333	71.77333333	63.42
		70.8666667	62.46	85.28	76.3
		63.2266667	55.16333	80.46	94.85667

		61.5833333	45.13	70.94333333	71.91
		67.47	67.8	83.48666667	66.16667
		61.9833333	49.88667	69.1	68.57333
		54.6233333	56.97667	69.00333333	61.35333
		54.0233333	56.36333	76.67	78.3
		50.6533333	62.10667	56.90666667	83.20667
		51.4066667	46.83333	58.88	56.75333
		57.01	50.21	55.84	64.84667
		61.58	58.72667	60.36666667	83.42
		52.8233333	57.44667	56.74666667	60.04
		63.0666667	60.91333	54.35333333	50.73667
		56.32	65.13333	56.97333333	78.93667
		61.8033333	57.97333	59.53	81.50667
		58.02	56.39667	56.56333333	77.01333
		59.46	55.6	60.84666667	88.03667
			51.95333	57.48666667	69.36
				51.58666667	65.66333
				50.18	60.42333
				51.33	52.62
				53.94	47.41
				56.95666667	42.36667
				55.54	65.67
				58.21	70.03333
				58.60666667	66.96333
				59.86333333	50.07333

Subject-4

Pull & Push strengths during 1, 5 & 10 Inch/Sec Routines

1 Inch per Second		5 Inch per Second		10 Inch per Second	
Pull	**Push**	**Pull**	**Push**	**Pull**	**Push**
52.72333333	41.21	55.4466667	34.41667	64.03333333	45.03667
53.12	46.7667	55.4766667	28.80667	60.34	61.20667
52.66666667	32.73	61.1466667	48.53667	53.79666667	33.71667
54.06666667	40.3933	66.61	37.03667	60.94666667	31.28
54.01333333	38.9933	68.6733333	42.23667	63.12	50.04
53.18	37.3767	69.4433333	45.53333	64.67333333	61.59667
51.24333333	34.0567	60.1366667	35.84333	61.80666667	52.61
51.07	32.95	57.2	27.33333	64.01333333	59.73667
56.54333333	31.3633	54.8	21.46667	61.12	52.25333
42.22	32.6133	54.0166667	39.33667	63.31	54.18667
41.74333333	28.4467	56.8433333	32.75333	63.52666667	45.34667
36.03333333	29.5833	57.7233333	39.53667	63.6	48.77
42.55666667	29.5133	56.63	32.75	65.69333333	47.74667
37.64666667		53.93	32.75	65.37333333	43.82
		54.8	23.51667	65.55	52.8
		57.0933333	21.81667	57.11	38.51333
		60.6666667	20.61	57.76666667	39.51
		61.2466667	17.64	49.10333333	35.5
		57.4633333	18.05333	45.76	29.32
		63.6133333	27.05667	50.89666667	30.45333
		59.3633333	56.01667	49.91	30.15
		63.0833333	52.65	52.74333333	27.64
		64.63	55.51	56.42333333	26.05667
		65.45	53.99333	54.19666667	25.55
		67.2633333	55.67	57.31333333	34.50333
		60.8666667	49.36333	54.22	28.20333
		61.8633333	46.54667	50.42	26.22667
		63.65	42.46333	50.52666667	24.87333

(TABLE Cont.)

		65.0566667	53.29667	56.28	32.59667
		63.74	47.28	44.95	21.65667
		63.3733333	45.78	49.62666667	24.57
		65.24	50.28333	43.7	27.76333
		63.02	50.27333	39.21	30.90667
		63.1166667	50.97	42.53333333	31.32
		62.4466667	41.19667	44.49666667	27.93333
		61.8066667	41.03	41.24666667	24.87667
		62.1066667	43.87	40.83333333	26.15333
		62.76	46.89	40.14333333	23.12
		61.6233333	35.91	42	22.36
		62.4966667	44.18	45.13333333	23.8
		59.8333333	37.11	45.89333333	22.44333
		61.9166667	28.7	44.78	25.51333
		56.0033333	33.56	47.21	25.27333
			38.08667	43.29666667	29.95333
				49.54	27.81667
				45.98666667	25.81667
				46.34	27.13667
				43.35666667	22.89667
				42.4	23.56
				37.76	25.24333
				42.29666667	23.89
				46.07	21.43667
				45.44333333	20.92

Subject-5

Pull & Push strengths during 1, 5 & 10 Inch/Sec Routines

1 Inch per Second		5 Inch per Second		10 Inch per Second	
Pull	**Push**	**Pull**	**Push**	**Pull**	**Push**
58.23333333	72.1933	43.9033333	53.1533	28.87666667	58.79667
61.29	72.7767	44.0466667	71.1533	30.11666667	67.76667
62.07333333	77.65	48.6233333	51.96	32.15	79.06667
59.74666667	77.6867	48.0066667	68.1933	34.78666667	83.09333
59.57	74.17	43.8966667	71.89667	36.11	76.21
58.44	72.65	53.22	78.48667	35.51333333	79.80667
57.16666667	81.91	62.2333	72.91	40.15666667	84.59667
52.03666667	74.53	54.4566667	75.53667	37.47666667	81.69333
49.43666667	76.9867	59.9266667	79.00333	41.03666667	76.52333
52.28666667	74.45	58.4766667	77.61667	38.24333333	80.49
45.56333333	79.4567	57.61	70.21333	39.26333333	79.98333
52.17333333	79.51	58.3	68.14333	37.54	79.90333
46.13	80.6433	57.23	75.45333	36.97666667	80.16333
45.56333333		56.49	80.36667	38.01333333	87.58667
		53.6833333	71.06	37.72	88.41667
		56.6133333	67.62	38.07333333	82.51667
		59.8366667	83.59667	39.65666667	81.77333
		53.4	64.54	36.24666667	83.57
		60.8366667	71.81	37.28666667	82.94333
		56.66	75.57	38.22	81.84667
		56.5	78.20667	37.04	77.16
		60.7133333	72.35667	40.17	80.48667
		62.4433333	69.84	38.55666667	76.91667
		65.3433333	70.84667	38.02333333	79.76667
		56.99	72.38	35.7	79.91
		57.2233333	67.26	36.16666667	74.38
		63.5066667	67.68667	37.16333333	76.17
		64.7233333	76.26667	37.07666667	74.65

(TABLE Cont.)

		65.0733333	73.34	37.29333333	82.68333
		63.8833333	71.20333	35.79	83.76333
		63.7033333	71.12667	38.75333333	76.94667
		63.09	76.55333	36.73333333	74.88667
		66.44	78.84333	37.75333333	78.02333
		59.88	79.10667	37.48333333	72.42
		68.1933333	82.33333	37.21666667	79.81333
		68.4833333	73.22	38.71	72.5
		65.0866667	74.56667	36.62	82.34667
		66.19	74.94333	41.94	75.22
		64.9433333	71.23333	37.38	80.19
		67.7	69.09333	42.27333333	76.03333
		61.62	75.04333	41.46666667	76.46
		61.5666667	73.38667	42.27333333	75.00333
		61.7133333	68.45333	39.74666667	81.47333
			71.65667	41.45	76.97333
				37.94666667	75.02333
				40.07666667	75.99667
				37.42	72.98667
				36.11333333	78.47
				34.11	71.96333
				39.24	71.68
				34.19	69.25
				32.61	70.04
				29.38333333	70.65333

Subject-6

Pull & Push strengths during 1, 5 & 10 Inch/Sec Routines

1 Inch per Second		5 Inch per Second		10 Inch per Second	
Pull	**Push**	**Pull**	**Push**	**Pull**	**Push**
50.17666667	47.2167	50.0966667	47.14333	41.97333333	42.49333
55.90333333	42.6133	55.07	47.32333	48.02	41.94333
47.56	48.8233	62.7433333	52.7	44.30333333	39.61
49.77666667	69.01	63.2	54.55	49.47333333	38.07
47.82333333	58.8	57.18	51.67667	48.02333333	40.34667
53.24333333	55.0467	56.7433333	66.74667	40.08666667	35.18333
52.45666667	57.4667	65.1133333	54.72	41.30333333	32.98667
47.34	43.38	60.7433333	63.77333	42.80666667	33.29
47.52666667	53.3933	73.3066667	48.99333	44.21	56.00667
43.04	51.6433	62.7166667	59.21333	41.73	30.65667
43.48	47.6433	51.01	85.88	39.88333333	28.98
42.97666667	57.89	55.8533333	55.03333	43.14	43.52667
41.59	52.12	55.58	56.02333	47.51666667	42.14
45.14333333		54.31	77.25333	41.26333333	34.24333
		59.6233333	58.15667	41.94	29.34
		66.0033333	66.82	44.69333333	35.46
		63.5733333	48.62	43.51333333	34.77667
		66.97	66.05	42.92333333	40.12333
		57.6666667	54.91667	43.06333333	43.68333
		55.9633333	59.05667	41.17666667	53.62667
		57.3333333	47.00333	40.18333333	41.89667
		60.0966667	43.86667	44.36333333	33.45
		53.5	40.01667	45.01333333	34.94
		52.8166667	38.32333	44.44333333	51.36667
		60.6433333	65.59667	48.58	49.08333
		63.2033333	54.12333	45.58666667	49.34333
		52.3233333	39.7	50.80333333	54.94333
		47.3833333	63.8	45.03	51.19333

(TABLE Cont.)

		52.8766667	48.52667	45.92666667	62.43667
		51.7566667	47.76	44.38	62.38333
		50.12	27.95333	44.31	33.57
		48.5033333	27.57	48.50333333	31.56333
		51.82	60.16667	48.65666667	42.03333
		57.3433333	42.59	49.11	64.1
		48.2033333	73.97333	48.27	73.54333
		55.0333333	67.86667	45.95	61.13333
		45.6733333	64.13333	46.35666667	42.43
		52.5333333	85.34667	48.37666667	38.00667
		49.8566667	25.18333	52.38	43.72333
		49.49	29.22	49.57666667	32.61333
		47.2566667	24.95	47.41	30.58667
		51.5433333	25.60333	42.10666667	57.58667
		45.74	32.72	42.35666667	82.18667
			51.99667	40.27	40.6
				47.79666667	34.76333
				46.84	33.53667
				45.32333333	42.53333
				46.29333333	83.38
				41.00666667	41.29667
				40.77	32.84333
				44.89333333	74.40333
				42.30666667	39.93333
				44.86333333	37.49667

Subject-7

Pull & Push strengths during 1, 5 & 10 Inch/Sec Routines

1 Inch per Second		5 Inch per Second		10 Inch per Second	
Pull	**Push**	**Pull**	**Push**	**Pull**	**Push**
62.43333333	65.73	90.2433333	59.31	103.06	37.51667
61.84666667	60.19	85.9866667	61.73333	91.89666667	37.42
57.49333333	60.31	87.6866667	52.94333	93.89333333	36.00667
59.61666667	48.6667	82.7733333	48.64	96.25	36.01333
55.67333333	52.46	79.11	58.73	97.29666667	33.23
62.92666667	53.0367	78.6533333	60.62	83.7	32.41667
57.92333333	55.03	77.2166667	49.05667	101.68	34.40333
59.95333333	46.1467	72.1933333	52.83667	92.01666667	44.16667
52.69666667	56.4133	79.3233333	50.96	89.88666667	52.29333
59.44333333	42.6033	77.56	58.34	93.37333333	53.06
48.94333333	43.19	83.52	58.45667	92.97333333	49.76333
64.17666667	39.4567	82.6633333	50.77667	97.98333333	49.55333
51.04666667	42.0233	77.1966667	59.77	95.39666667	44.06
49.22		78.51	60.89	98.84	38.93
		84.1066667	64.15333	98.83	36.22
		74.0833333	54.06	102.2966667	36.01
		74.08	51.6	98.38666667	38.12667
		57.9566667	46.93	101.6533333	37.81333
		66.3366667	42.05	91.13666667	33.83667
		57.1766667	41.29667	93.96333333	44.63333
		63.3766667	40.88667	85.42	44.01667
		62.6833333	40.17333	87.48666667	41.36667
		64.2366667	44.52	89.9	45.8
		60.9666667	45.06	89.22666667	40.73
		60.1966667	49.85	93.97333333	45.84
		62.5233333	47.94	97.80333333	41.49333
		58.1533333	43.85333	95.4	37.29667
		56.77	38.72	89.46666667	37.66667

(TABLE Cont.)

		54.2566667	45.96	99.83	65.71333
		55.2333333	42.44667	94.38333333	61.95333
		55.65	48.28	84.50666667	57.09
		58.8366667	51.87667	86.90666667	60.95333
		64.39	48.48667	84.92666667	68.44667
		62.4133333	43.5	81.39666667	55.08333
		63.79	44.34667	79.89	57.87333
		61.0566667	44.15333	79.28333333	54.71
		63.9233333	40.51333	81.62666667	61.00333
		50.17	37.71333	81.7	58.62333
		47.69	39.86	74.16333333	61.74667
		62.2866667	41.78	75.90333333	50.87667
		62.0333333	44.39667	78.76333333	63.8
		55.49	42.42333	77.82333333	59.19
		40.65	34.42667	77.78333333	41.48667
			32.17	72.13	45.20333
				73.67333333	42.64
				74.93	49.48667
				71.90666667	52.94
				76.06666667	50.5
				79.2	58.90333
				81.2	65.25333
				72.11333333	64.07667
				67.76666667	48.21
				66.39	46.32333

Subject-8

Pull & Push strengths during 1, 5 & 10 Inch/Sec Routines

1 Inch per Second		5 Inch per Second		10 Inch per Second	
Pull	**Push**	**Pull**	**Push**	**Pull**	**Push**
56.17666667	29.5867	60.68	29.88667	61.69333333	30.27667
49.54666667	30.49	62.2366667	29.40333	63.21666667	32.00333
55.28333333	23.2433	62.0666667	28.63667	66.33666667	33.65667
57.17333333	19.8633	64.8733333	31.93667	69.23666667	31.98667
56.08666667	55.7933	64.2866667	37.34333	75.01333333	27.94667
41.51666667	65.5767	61.99	30.23333	66.16666667	24.54333
43.96666667	52.5267	55.76	28.64667	63.91666667	25.53667
57.67333333	28.4033	63.23	28.61333	67.58666667	23.24333
60.63666667	24.3767	59.152	31.14	73.85	19.09333
57.73666667	28.4367	60.68	31.90333	74.7	23.90333
60.52	31.0467	62.7733333	39.26	75.99	19.75333
57.22	43.5633	60.63	35.10333	69.79666667	24.36667
50.31666667	68.1633	61.5933333	33.93333	63.02333333	22.18
46.32		60.6466667	37.93333	68.60666667	17.58
		60.1933333	37.83667	73.14	22.74333
		56.98	42.19333	75.83666667	23.53667
		56.89	25.85667	65.90333333	22.03667
		58.6966667	27.18667	72.33	22.81333
		59.63	28.39333	70.94666667	19.12333
		63.4533333	26.02333	70.99	18.72667
		62.5833333	22.64	69.76	19.83333
		62.14	27.01667	78.01666667	22.57333
		59.66	26.23333	69.57333333	20.59333
		61.2233333	22.57333	68.68666667	23.07
		60.9433333	23.73333	74.91333333	24.27333
		56.8933333	26.85	74.21	22.73
		57.7933333	22.42333	74.19333333	22.58333
		64.8966667	21.6	78.10333333	23.93

		65.11	22.23	77.95333333	25.77667
		65.4466667	25.22	71.96333333	22.68333
		65.45	28.67	71.00333333	28.70333
		66.44	25.26	73.58333333	24.74333
		65.0866667	24.08667	73.92	27.22333
		65.5266667	24.25667	72.76666667	27.45
		64.2266667	24.22	73.66	24.87
		66.44	30.37667	69.49333333	29.42667
		64.31	25.99333	70.63	25.05333
		61.3333333	28.195	68.6	26.58667
		61.4833333	23.75	72.87	26.20667
		59.3833333	20.27333	74.58333333	26.67
		61.1733333	27.56	75.39333333	29.42667
		65.11	19.22333	73.29666667	26.99667
		60.48	27.23	77.91	27.51333
			25.72667	73.92	24.80667
				74.33	24.77333
				65.35333333	29.73667
				70.78666667	30.41
				72.00666667	28.98333
				73.55	27.59
				75.30666667	23.84667
				69.09666667	25.62333
				69.86333333	26.33333
				70.74333333	27.3

Subject-9

Pull & Push strengths during 1, 5 & 10 Inch/Sec Routines

1 Inch per Second		**5 Inch per Second**		**10 Inch per Second**	
Pull	**Push**	**Pull**	**Push**	**Pull**	**Push**
		71.8633333	84.85667	71.28333333	55.19667
		70.66	76.05333	68.65333333	56.3
		66.16	64.31333	72.88	65.20667
		69.6433333	71.36	74.23	57.20667
		68.87	73.22333	70.91666667	54.09
		68.8266667	67.88	68.13666667	63.12333
		67.4866667	76.46667	61.4	57.80667
		71.1466667	81.26	67.87666667	53.54
		75.32241	81.67	63.61666667	60.59667
		76.21	66.96667	69.58	54.04
		69.6333333	81.44	65	61.8
		73.3866667	79.06667	68.24	78.14667
		75.0233333	70.21	68.75333333	73.74
		73.7633333	75.51667	67.73666667	72.24
		71.98	81.83333	71.87	64.65667
		68.9366667	76.01	67.21666667	73.59
		66.1666667	72.74333	72.62	61.60333
		68.0633333	72.34333	68.84	50.18
		60.29	77.03333	68.06666667	58.72333
		66.8	76.72	68.79333333	59.41333
		65.9433333	74.49667	66.31333333	64.81
		62.1666667	73.96667	73.30666667	64.74333
		65.1233333	82.77667	66.19	56.85333
		60.2633333	69.61333	65.53666667	64.59333
		65.83	77.14667	66.29	60.23
		65.82	77.32	67.24	63.66333
		70.24	73.96333	66.12	63.74667
		66.0733333	82.03333	65.36333333	71.35

		67.9666667	75.48333	69.37333333	67.05667
		61.8833333	86.25	69.95333333	59.13667
		64.3733333	81.34667	66.69333333	82.00333
		64.4466667	73.13	72.92	69.43333
		59.9233333	77.38333	65.45666667	70.93333
		65.6166667	75.88667	70.1	77.73333
		66.5633333	71.46	72.68666667	77.89333
		65.8833333	62.09667	69.93333333	73.81
		65.7133333	62.02667	69.58	65.99667
		68.74	62.48333	67.33666667	63.86
		66.81	74.93667	62.93666667	72.06333
		66.5033333	70.28667	63.21666667	74
		74.43	67.06	67.11	74.28667
		78.51	69.95	68.58666667	72.22333
		75.48	73.51667	69.20333333	76.34
			74.63667	75.43	67.32667
				62.55666667	77.93667
				67.85666667	66.39
				66.17	61.31667
				76.32666667	74.57333
				72.47333333	62.25667
				71.69333333	68.35667
				66.55666667	74.09333
				73.17666667	67.63667
				67.64333333	61.59667

Subject-10

Pull & Push strengths during 1, 5 & 10 Inch/Sec Routines

1 Inch per Second		5 Inch per Second		10 Inch per Second	
Pull	**Push**	**Pull**	**Push**	**Pull**	**Push**
49.91333333	56.5233	64.6966667	70.66333	74.85666667	99.91333
60.48	57.5933	63.2466667	60.79333	87.70666667	109.61
65.98	57.8233	72.8733333	64.12667	84.64333333	94.97667
64.23333333	59.47	86.0766667	66.71667	97.06666667	88.20667
64.48	60.2967	81.98	78.73667	94.26666667	81.30667
58.67666667	58.8367	87.6233333	77.71667	97.42	101.3533
55.15	56.5567	89.59	87.91	99.83666667	94.01667
52.71666667	63.6467	94.2233333	76.51333	99.96666667	98.54333
69.00666667	62.3467	92.23	76.67333	104.1	87.72667
58.86666667	59.97	100.18	72.15333	86.08	93.85
59.86	59.1433	94.01	75.78	60.87666667	90.37
64.85333333	62.9933	99.1833333	80.43333	76.59	99.77667
63.47	61.6	102.05	74.15333	93.41666667	93.38667
56.89		98.3633333	73.87333	96.18	87.42
		99.3966667	74.19	86.57666667	77.81
		101.943333	76.24333	94.55333333	90.64
		92.0966667	74.61	90.21666667	85.13667
		93.9633333	78.13	77.55666667	74.81333
		94.42	70.21333	86.73333333	89.98333
		89.34	79.82	96.01666667	94.88667
		92.8866667	79.72	99.48666667	103.8267
		94.9966667	70.92333	102.8166667	90.73
		87.48	76.05667	101.1266667	95.04667
		100.893333	76.75	95.39333333	85.58333
		96.9	78.38667	103.33	85.54667
		98.68	75.34667	107.5066667	92.58
		92.8833333	71.95667	101.6933333	92.15667
		100.52	74.44667	107.8366667	103.57

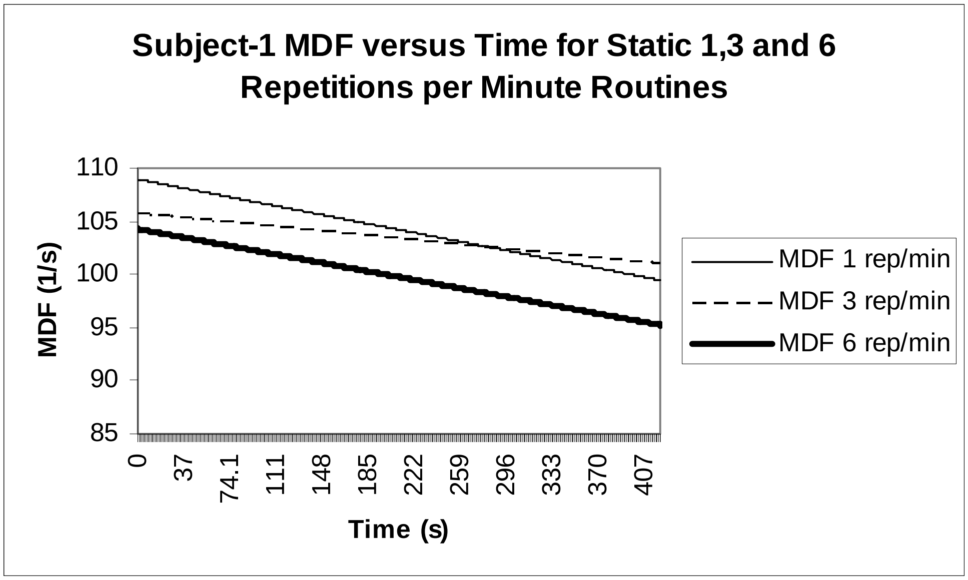
(TABLE Cont.)

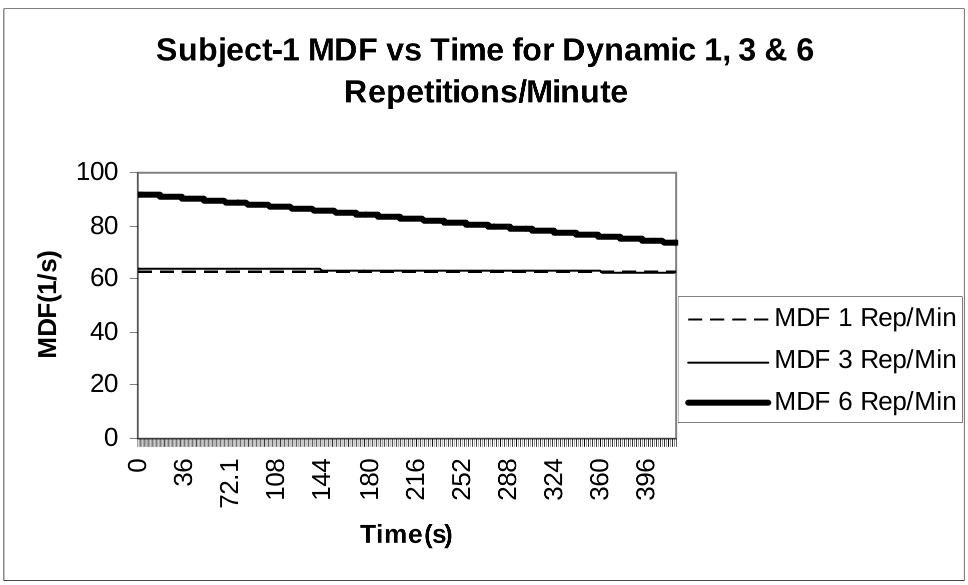
		100.97	80.90333	104.37	99.08
		102.446667	79.18	109.15	92.81
		97.64	67.85667	98.77	90.91
		100.143333	65.81333	92.41	90.16
		103.8	73.67	96.68	103.29
		102.25	71.72667	93.11	103.60
		91.2333333	74.14333	92.58	100.24
		101.916667	74.03667	104.15	107.43
		95.7466667	78.69	101.89	96.38
		98.9066667	77.90	100.94	91.37
		103.303333	75.22	99.46	88.94
		98.5566667	69.69	101.73	101.18
		94.89	69.24	108.78	83.87
		92.8866667	64.75	88.35	85.38
		100.94	66.92	97.99	83.07
			66.49	94.21	69.19
				86.69	82.98
				86.68	70.12
				88.85	66.37
				90.47	70.76
				91.38	80.45
				90.69	87.20
				92.56	71.25
				98.78	85.27
				86.01	82.19

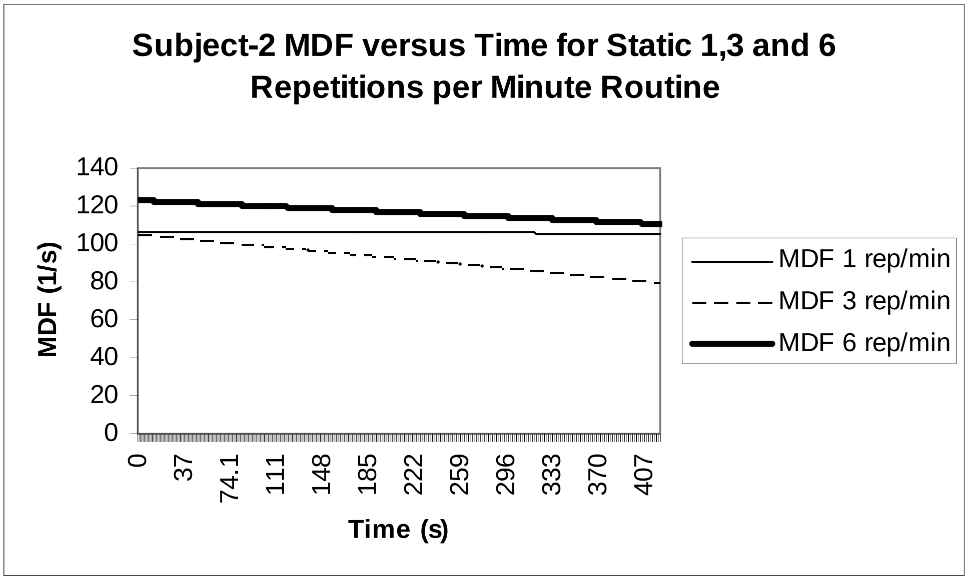
APPENDIX-C

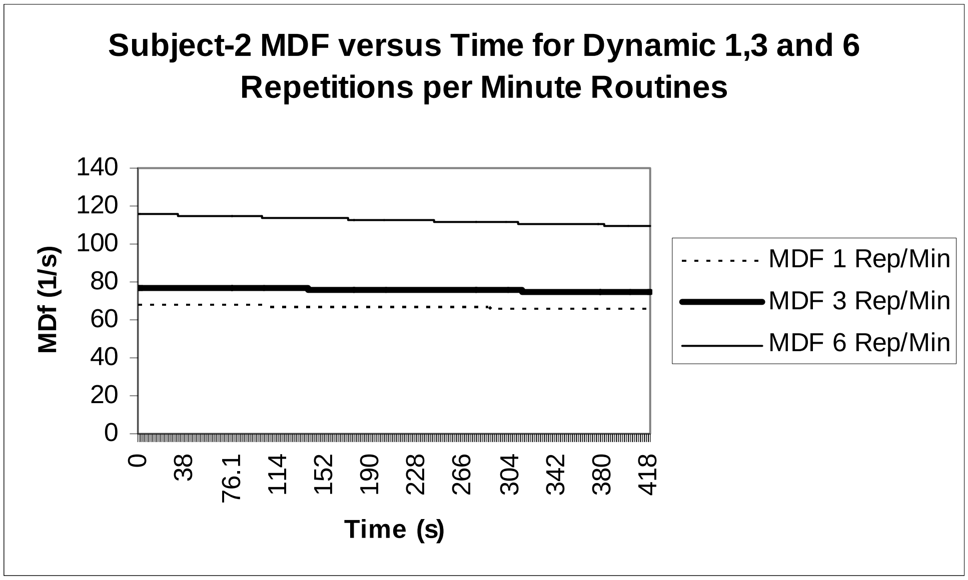
EMG DATA OF SUBJECTS DURING DIFFERENT STRENGTH TESTING ROUTINES

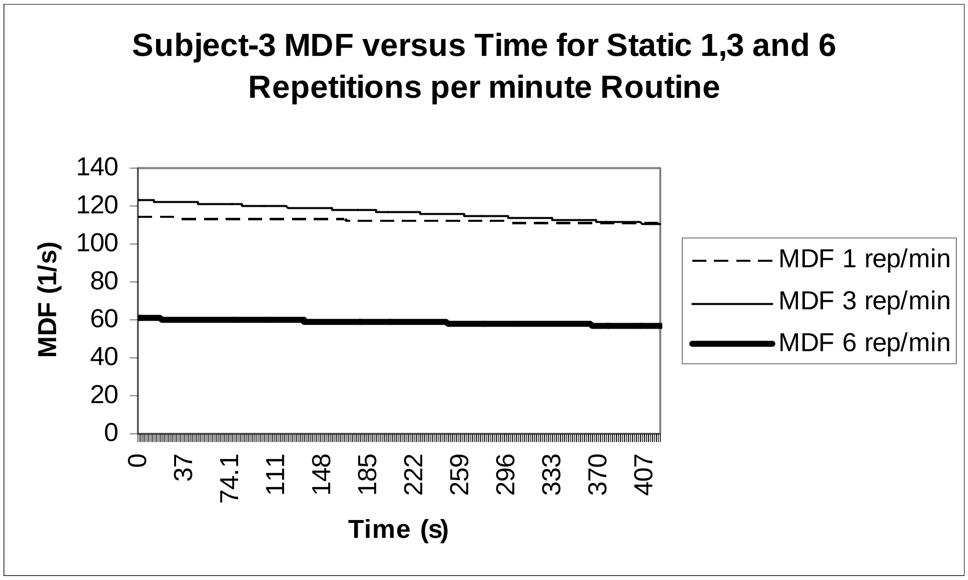
EMG Data of Subjects from Part-1 of the study

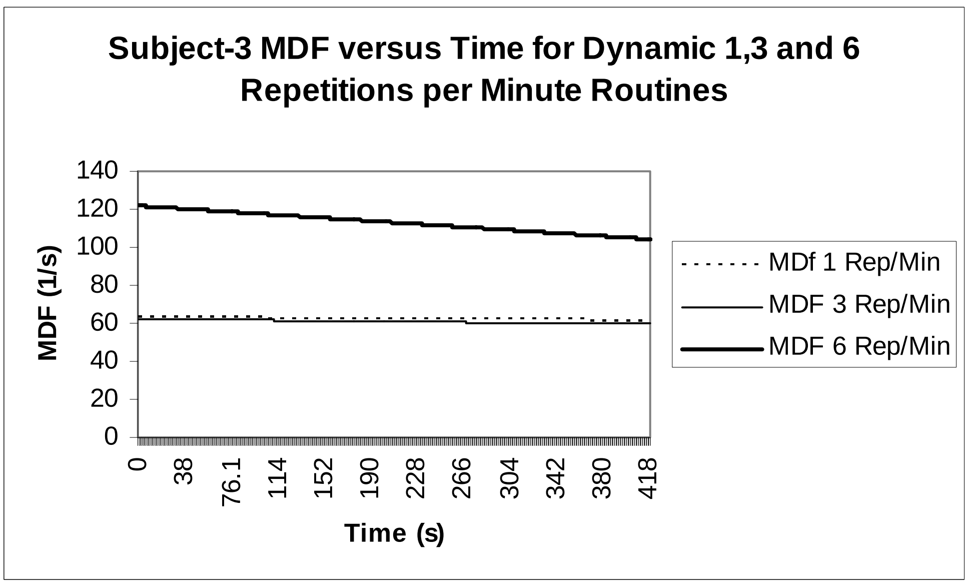


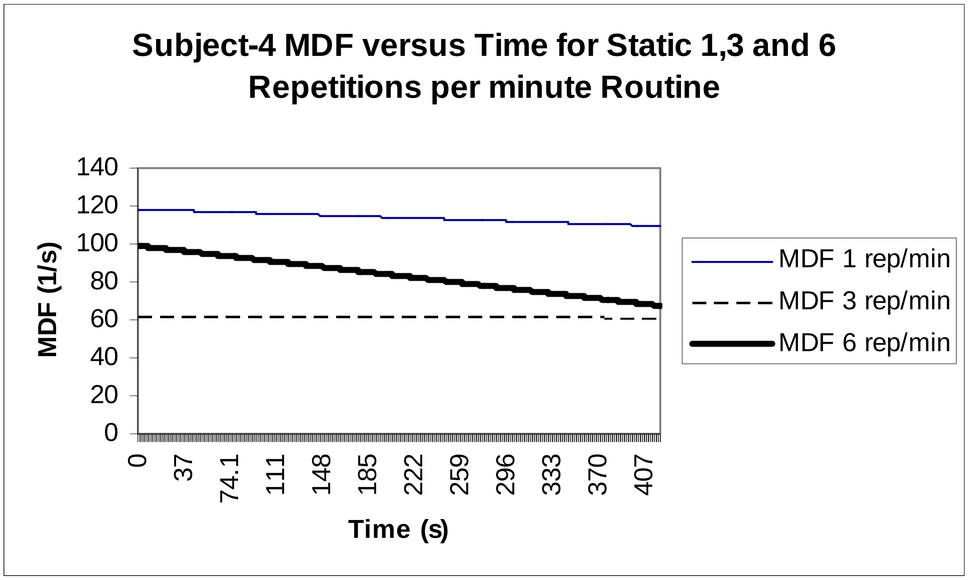



Subject-2 MDF versus Time for Static 1,3 and 6 Repetitions per Minute Routine
140
120
100
80
60
40
20
0
MDF (1/s)
0
37
74.1
111
148
185
222
259
296
333
370
407
Time (s)
MDF 1 rep/min
MDF 3 rep/min
MDF 6 rep/min

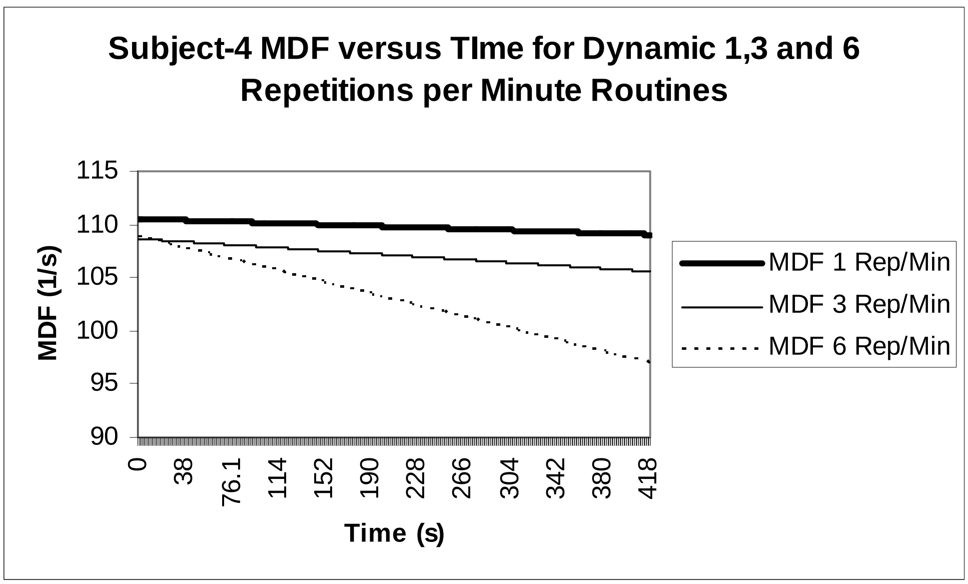

Subject-2 MDF versus Time for Dynamic 1,3 and 6 Repetitions per Minute Routines
140
120
100
80
60
40
20
0
MDf (1/s)
0
38
76.1
114
152
190
228
266
304
342
380
418
Time (s)
MDF 1 Rep/Min
MDF 3 Rep/Min
MDF 6 Rep/Min


Subject-3 MDF versus Time for Static 1,3 and 6 Repetitions per minute Routine
MDF (1/s)
140
120
100
80
60
40
20
0
0
37
74.1
111
148
185
222
259
296
333
370
407
Time (s)
MDF 1 rep/min
MDF 3 rep/min
MDF 6 rep/min

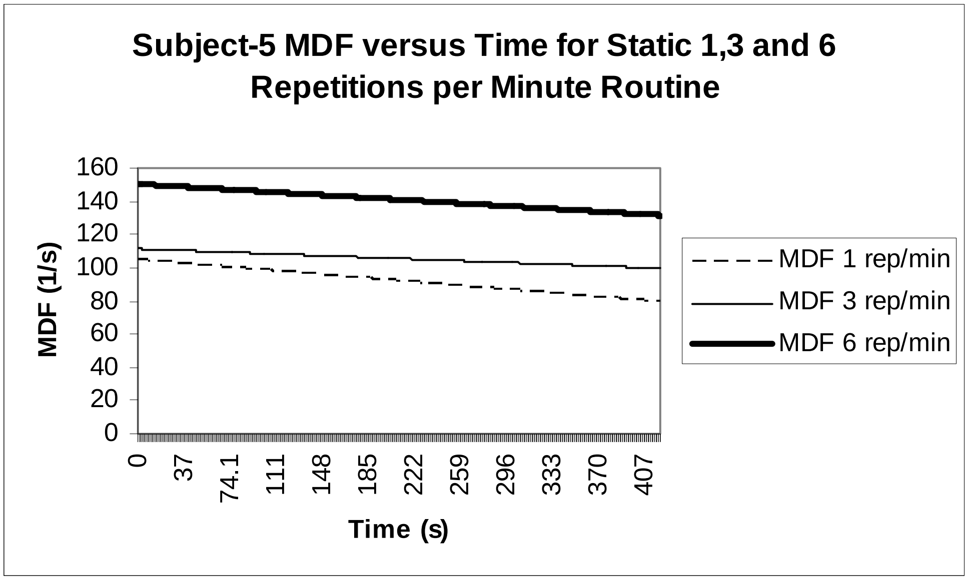

Subject-3 MDF versus Time for Dynamic 1,3 and 6 Repetitions per Minute Routines
MDF (1/s)
140
120
100
80
60
40
20
0
0
38
76.1
114
152
190
228
266
304
342
380
418
Time (s)
MDf 1 Rep/Min
MDF 3 Rep/Min
MDF 6 Rep/Min

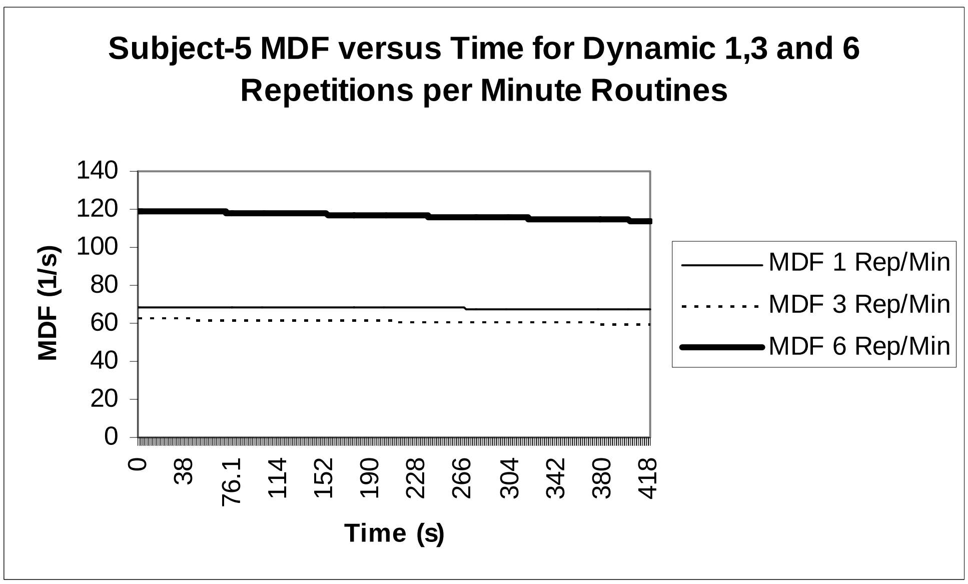


Subject-4 MDF versus Time for Static 1,3 and 6 Repetitions per minute Routine
MDF (1/s)
140
120
100
80
60
40
20
0
0
37
74.1
111
148
185
222
259
296
333
370
407
Time (s)
MDF 1 rep/min
MDF 3 rep/min
MDF 6 rep/min

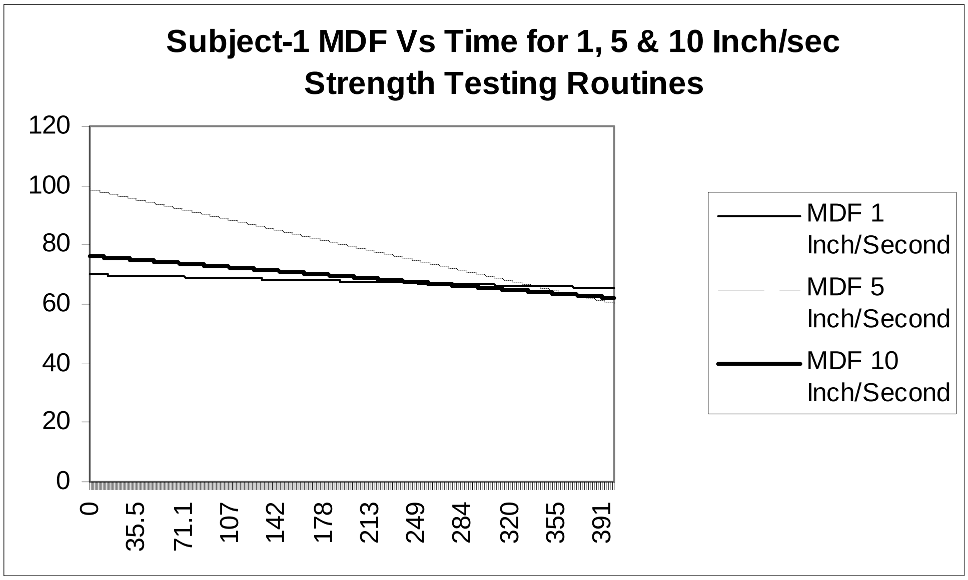


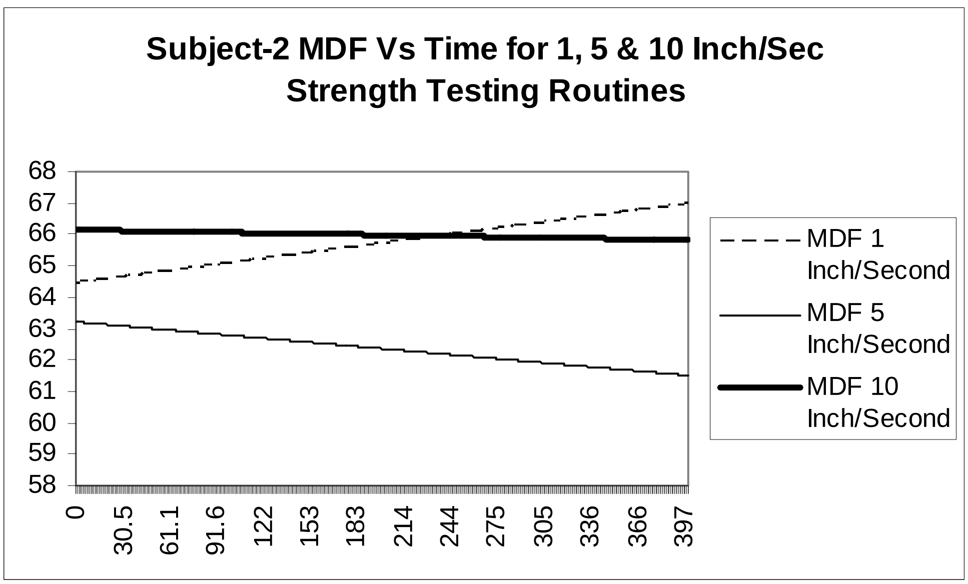
Subject-4 MDF versus TIme for Dynamic 1,3 and 6 Repetitions per Minute Routines
MDF (1/s)
115
110
105
100
95
90
0
38
76.1
114
152
190
228
266
304
342
380
418
Time (s)
MDF 1 Rep/Min
MDF 3 Rep/Min
MDF 6 Rep/Min

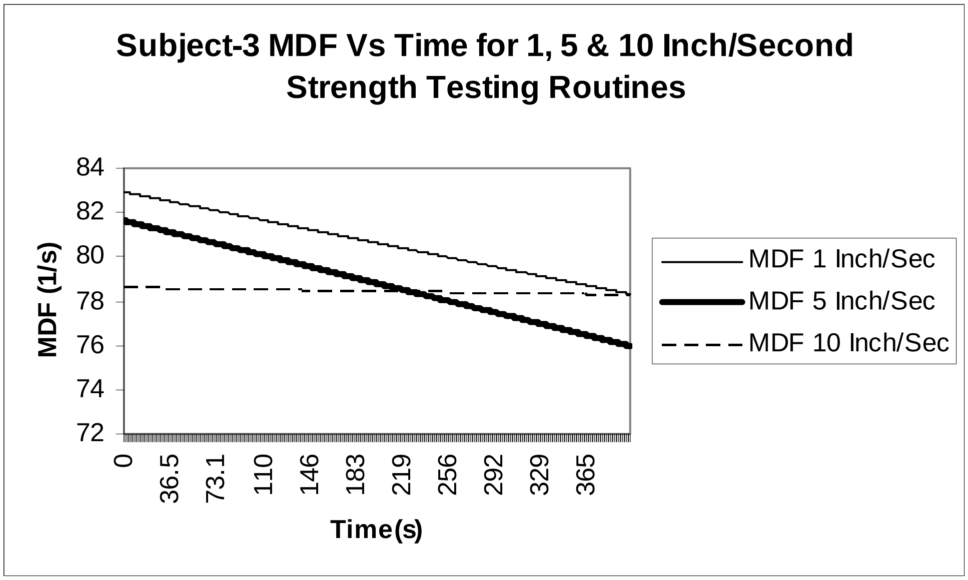

Subject-5 MDF versus Time for Static 1,3 and 6 Repetitions per Minute Routine
160
140
120
100
80
60
40
20
0
MDF (1/s)
0
37
74.1
111
148
185
222
259
296
333
370
407
Time (s)
MDF 1 rep/min
MDF 3 rep/min
MDF 6 rep/min

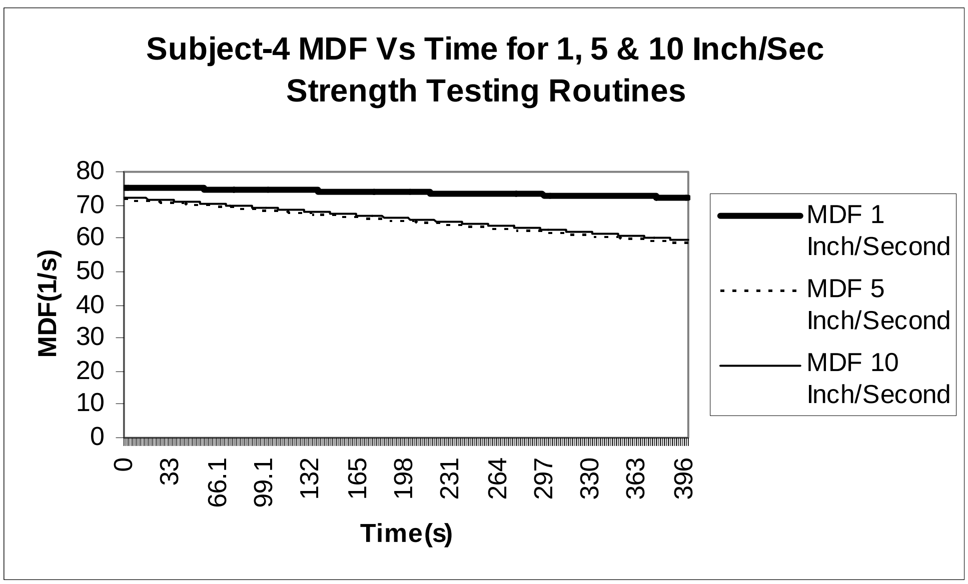

Subject-5 MDF versus Time for Dynamic 1,3 and 6 Repetitions per Minute Routines
140
120
100
80
60
40
20
0
MDF (1/s)
0
38
76.1
114
152
190
228
266
304
342
380
418
Time (s)
MDF 1 Rep/Min
MDF 3 Rep/Min
MDF 6 Rep/Min

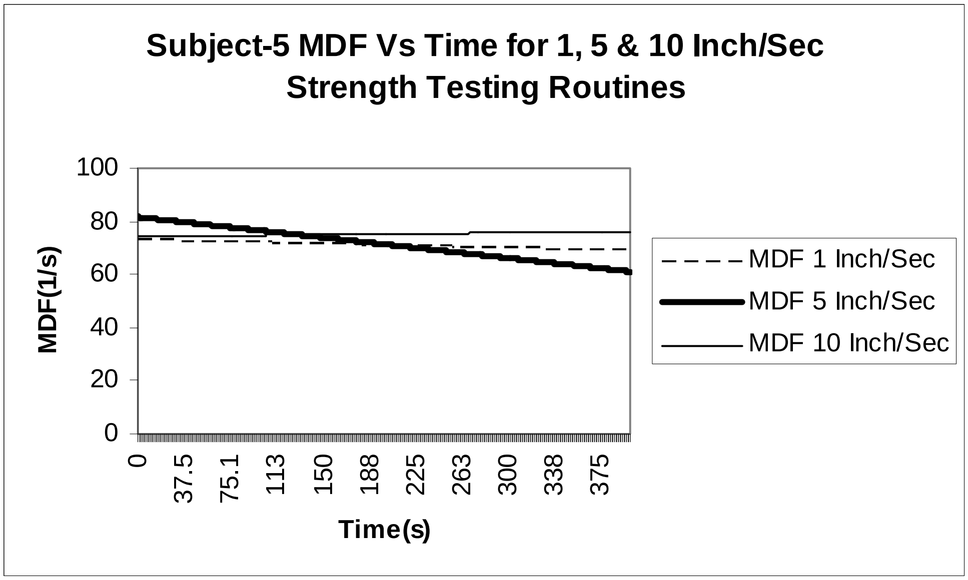
EMG Data of Subjects from Part-2 of the study

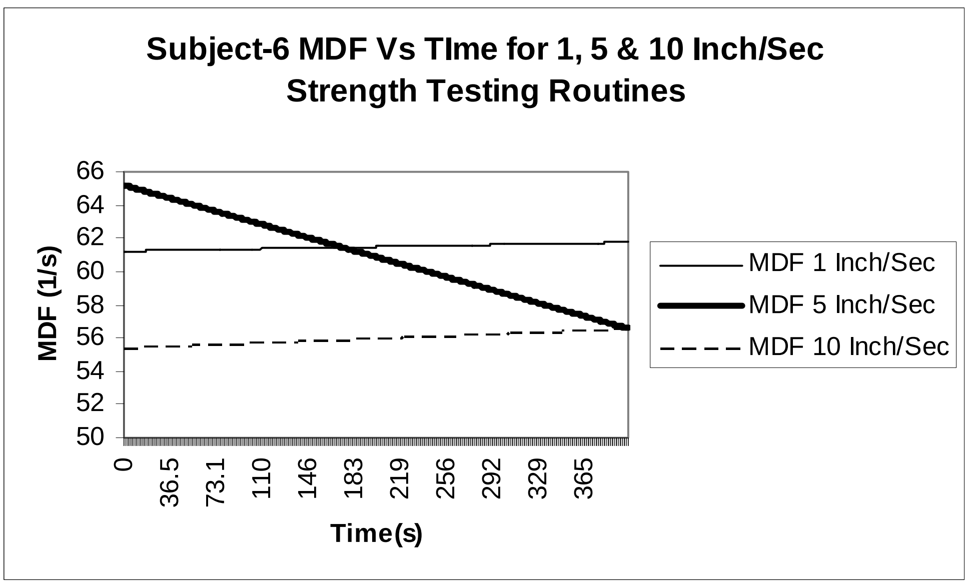


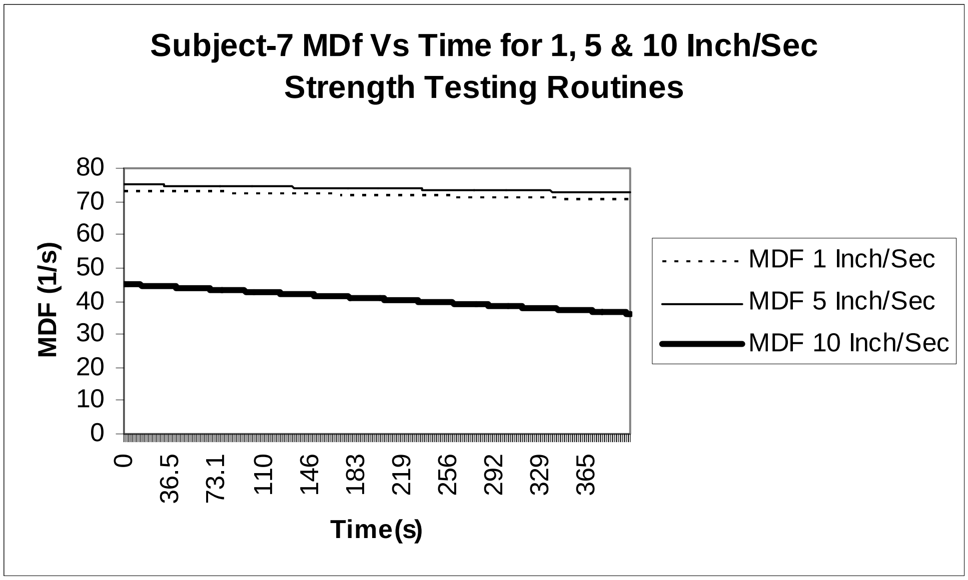


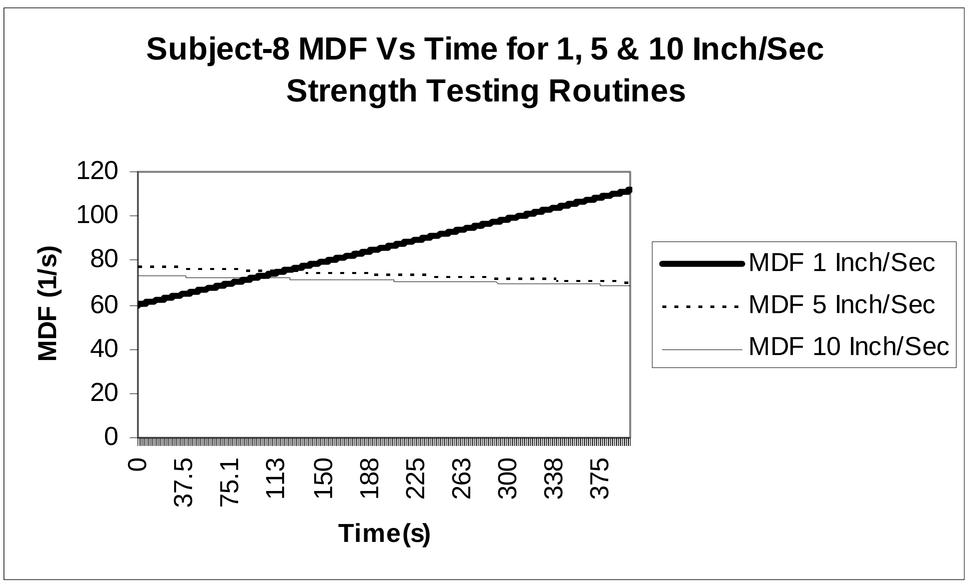

Subject-3 MDF Vs Time for 1, 5 & 10 Inch/Second Strength Testing Routines
84
82
80
78
76
74
72
MDF (1/s)
0
36.5
73.1
110
146
183
219
256
292
329
365
Time(s)
MDF 1 Inch/Sec
MDF 5 Inch/Sec
MDF 10 Inch/Sec

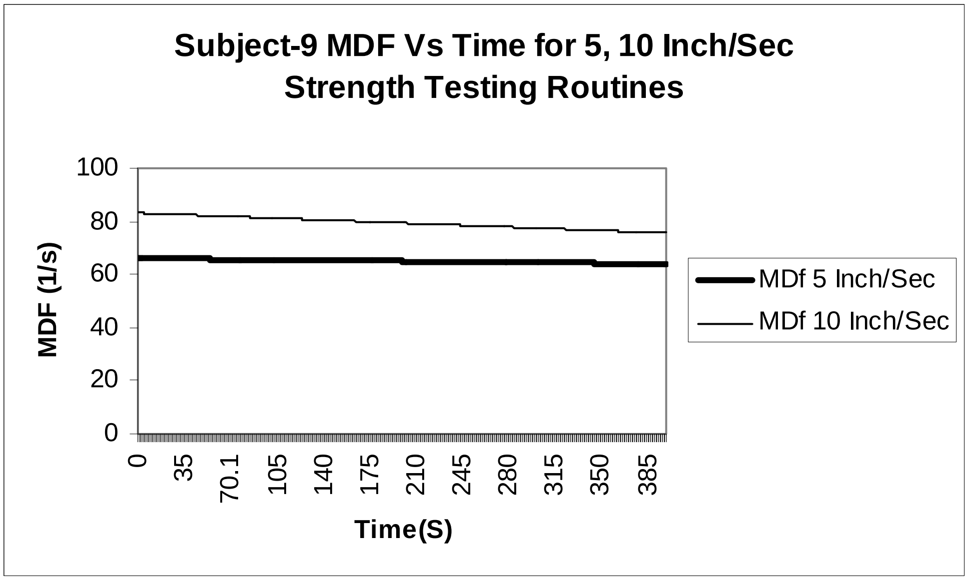

Subject-4 MDF Vs Time for 1, 5 & 10 Inch/Sec Strength Testing Routines
80
70
60
50
40
30
20
10
0
MDF(1/s)
0
33
66.1
99.1
132
165
198
231
264
297
330
363
396
Time(s)
MDF 1 Inch/Second
MDF 5 Inch/Second
MDF 10 Inch/Second

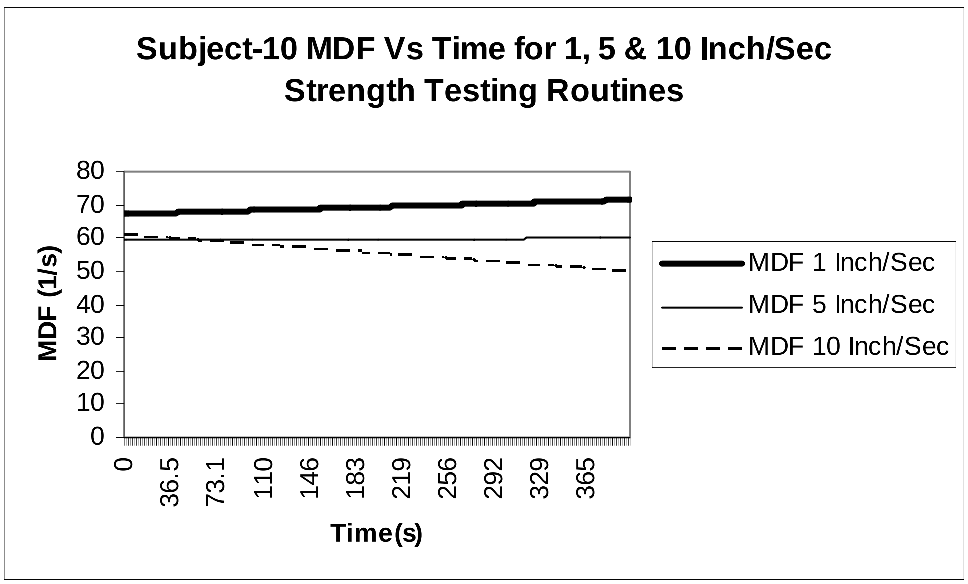

Subject-5 MDF Vs Time for 1, 5 & 10 Inch/Sec Strength Testing Routines
MDF(1/s)
100
80
60
40
20
0
0
37.5
75.1
113
150
188
225
263
300
338
375
Time(s)
MDF 1 Inch/Sec
MDF 5 Inch/Sec
MDF 10 Inch/Sec


Subject-6 MDF Vs TIme for 1, 5 & 10 Inch/Sec Strength Testing Routines
MDF (1/s)
66
64
62
60
58
56
54
52
50
0
36.5
73.1
110
146
183
219
256
292
329
365
Time(s)
MDF 1 Inch/Sec
MDF 5 Inch/Sec
MDF 10 Inch/Sec


Subject-7 MDf Vs Time for 1, 5 & 10 Inch/Sec
Strength Testing Routines
80
70
60
50
40
30
20
10
0
MDF (1/s)
0
36.5
73.1
110
146
183
219
256
292
329
365
Time(s)
MDF 1 Inch/Sec
MDF 5 Inch/Sec
MDF 10 Inch/Sec


Subject-8 MDF Vs Time for 1, 5 & 10 Inch/Sec
Strength Testing Routines
120
100
80
60
40
20
0
MDF (1/s)
0
37.5
75.1
113
150
188
225
263
300
338
375
Time(s)
MDF 1 Inch/Sec
MDF 5 Inch/Sec
MDF 10 Inch/Sec


Subject-9 MDF Vs Time for 5, 10 Inch/Sec
Strength Testing Routines
100
80
60
40
20
0
MDF (1/s)
0
35
70.1
105
140
175
210
245
280
315
350
385
Time(S)
MDf 5 Inch/Sec
MDf 10 Inch/Sec


Subject-10 MDF Vs Time for 1, 5 & 10 Inch/Sec
Strength Testing Routines
80
70
60
50
40
30
20
10
0
MDF (1/s)
0
36.5
73.1
110
146
183
219
256
292
329
365
Time(s)
MDF 1 Inch/Sec
MDF 5 Inch/Sec
MDF 10 Inch/Sec

VITA

Sai Chaitanya Reddy Bogolu was born in Kurnool, India, on May 30, 1982. He received a Bachelor of Technology in Electronics and Instrumentation Engineering degree from Jawaharlal Nehru Technological University in Andhra Pradesh, India, (April 2003). He is currently a candidate for the degree of Master of Science in Industrial Engineering in the department of Industrial Engineering at Louisiana State University, Baton Rouge, Louisiana. He is expected to receive the degree in May 2006.