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COMPARISON OF SELECTED KINETIC PERFORMANCE
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METHODS

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COMPARISON OF SELECTED KINETIC PERFORMANCE VARIABLES FROM TWO DIFFERENT WEIGHT TRAINING METHODS

By

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ABSTRACT

COMPARISON OF SELECTED KINETIC PERFORMANCE VARIABLES FROM TWO DIFFERENT WEIGHT TRAINING METHODS

By

Jerome Michael Learman

The purpose of this study was to examine if participants (n = 31) trained two times per week over a 15 week period at a high velocity using lighter weight (i.e., 35% of 1 RM), could they increase the amount of force, peak velocity, and time to peak velocity 1 RM, as much as if they had trained at a high force (i.e., 80% of 1 RM)? As the study used high school male and female as participants, it also examined if gendered affect their ability to increase the amount of maximum force (1 RM), peak velocity generated when lifting lighter weights (i.e., 35% of 1 RM), and the time to peak velocity? Lastly the study examined how two different weight training programs affect biomechanical parameters over 15 weeks?

An analysis of the data found that group had no effect on change in 1 RM or peak velocity and both groups had a significant increase from pre-test to post-test, but between the two different training groups the difference was not significant. However the data showed that participants from both groups had a significant increase in time to peak velocity from pre-test to post-test, but between the two different training groups the difference was significant. Gender did have an effect on change in 1 RM and peak velocity. The shape of the velocity patterns did not change significantly depending on which weight training program the subject used, but they did change in amplitude. The minimum and maximum values of the velocity curves increased. This supports the contention that training occurred for both groups.

To my family for their help and support.

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CHAPTER 1

INTRODUCTION

Resistance training impacts several body systems, including muscular, endocrine, skeletal, metabolic, immune, neural, and respiratory. According to Reeves, Laskowski, and Smith (1998), more than 45 million Americans regularly train with weights.

For purposes of this study, the term "weight training" refers to exercises that use weights for resistance to build strength and muscle mass. Several different styles of weight training exist. At present, the use of machines may be the most common method of fitness-related weight training. Machines allow exercisers to circuit train or to focus on individual muscles or muscle groups (e.g., deltoids, hamstrings).

Despite the fact that weight training, using either free weights or weight-stack machines, is the most widely used form of resistance exercise, according to Morrissey, Harman, and Johnson (1995), all but two studies (Palmitri (1987) and Young and Bilby (1993)), devoted to resistance training velocity, have relied upon isokinetic machines to provide resistance. Bell and Wenger (1992) suggest that the isokinetic training has only been shown to be a successful modality in rehabilitation programs. Therefore, there remains a large void in the literature of applicable studies on weight training.

Purpose of the Study

The purpose of this study is to examine different training methods and modalities (high velocity and high force) used in common practice by athletes and others who weight train. More specifically the purpose of this study was to answer the following research questions:

1. If participants trained two times per week over a 15 week period at a high velocity using lighter weight (i.e., 35% of 1 RM), can they increase the amount of force, as measured by 1 RM, as much as if they had trained at a high force (i.e., 80% of 1 RM)?
2. If participants trained two times per week over a 15 week period at a high force (i.e., 80% of 1 RM at a self-selected frequency of repetition), can they increase the peak velocity generated when lifting lighter weights (i.e., 35% of 1 RM) and the time to peak velocity as much as if they had trained at a lighter weight (i.e., 35% of 1 RM at a high frequency of repetition)?
3. If high school male and female participants trained two times per week over a 15 week period with the same protocol, does gender affect their ability to increase the amount of maximum force (1 RM), peak velocity generated when lifting lighter weights (i.e., 35% of 1 RM), and the time to peak velocity?
4. How do two different weight training programs (i.e., high frequency at 35% of 1 RM and high force associated with 80% of 1 RM at a self-selected frequency of repetition) affect biomechanical parameters (i.e., complete velocity pattern of the weight for all repetitions of weight taken every 10 milliseconds) over 15 weeks?

The answers to these research questions could greatly change the methods used to weight train athletes and other populations in the future. Given the differences in the finding of other studies such as Kramer and Newton (1994), Cronin, McNair, and Marshall (2001a and 2001b), Apor (1987), Bell and Wenger (1992), Keeler et al. (2001), Young, McDowell, and Scarlett (2001), Jones et al. (2001), and Schmidtbleicher and

Haralambie (1981), which used different loads for resistance training, the results will help clarify the benefits of training at various loads.

Statement of Each Hypothesis

1. No difference will be found between the high velocity and high force groups from pre-test to post-test in the change of 1 RM, change in maximum velocity when lifting 35% of 1 RM, or change in time to maximum velocity when lifting 35% of 1 RM.
2. No differences between genders will be found from pre-test to post-test in 1 RM, maximum velocity when lifting 35% of 1 RM, or time to maximum velocity when lifting 35% of 1 RM.
3. The variables of gender, weight, height, maturational state, arm girth, arm skin fold, and arm length will not be predictors of the dependent variables (1 RM, maximum velocity, and time to maximum velocity when lifting 35% of 1 RM).

Glossary of Terms

- **One repetition maximum (1 RM)**: the greatest amount of weight that a person can lift at one time while still keeping proper form in a designated exercise
- **Absolute strength**: maximum contractile force of a muscle, usually occurring during eccentric contraction
- **Circuit training**: technique that minimizes rest between sets and exercises; each exercise is done in succession with minimal rest between stations; each station involves a different exercise or weight training machine

- **Concentric contraction**: muscle shortens in opposition to a resistance; tension produced varies with acceleration of the resistance; muscle tension is greater than the resistance
- **Contrast training**: training method that uses both high force slow-velocity and low-force high-velocity when working out to increase power and/or strength
- **Cross training effect**: referred to in motor learning as contra-lateral training; when one side of the body is trained, and increase in performance is found in the untrained opposite side of the body
- **Eccentric contraction**: muscle lengthens while attempting to lift a resistance; while tension produced varies with the deceleration of a resistance, muscle tension is less than the resistance
- **Force curve or force-velocity curve**: the relationship of force to velocity for skeletal muscle tissue (see Figure 1); for any given force, the maximum speed of shortening or lengthening of a muscle; the Hill equation (Winter, 1990), best known of the force-velocity equations, mathematically describes the fact that light loads can be lifted quickly but heavy loads only slowly; although it is often stated that maximum muscle force is available at zero velocity (isometric action), the highest loads are achieved during eccentric muscle action

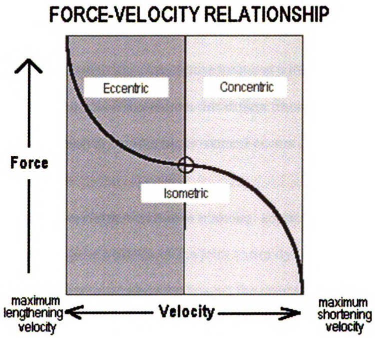


Figure 1. Force-Velocity Curve of Muscle Contraction

- **High force training**: resistance training using a weight close to a participant's 1 RM
- **High power training**: resistance training using a weight that optimizes for power (assumed to be around 30% of a participant's 1 RM (Newton & Kraemer, 1994)); due to the fact that high power is associated with moving at maximum repetition frequency, it is also known as the <u>high velocity training</u>
- **High velocity force production**: the ability to contract muscles as rapidly as possible and still produce force, the force-velocity curve tells us the amount of force that can be produces at a high velocity is limited
- **Isokinetic training**: application of muscular torque at a joint when the angular velocity of a segment of the joint is held to a constant speed; this differs from isotonic training in that in isokinetic training the speed of contraction is controlled

by an accommodating machine resistance (i.e., the greater the torque applied by the user, the greater the resistance torque provided by the machine)

- **Isometric training**: application of muscular torque at a joint when the joint angle of a segment of the joint is held constant; this differs from isotonic and isokinetic training in that in isometric training no movement occurs (i.e., no change in muscle length occurs)
- **Isotonic training or variable resistance training**: application of muscular torque at a joint when the angular velocity of the joint varies dynamically on the basis of variations in muscular torque generated against the resistance
- **Lock out**: maximum extension of a joint to a position where neither muscular extensor torque nor muscular flexor torque are required to maintain joint position and position of an externally supported load; joint compression is experienced in this position (e.g., when the elbow joints are fully extended during a bench press)
- **Maximum mechanical power**: measure of the highest power output during a particular exercise or activity as measured by the rate of work against an external load
- **Maximum rate of force development**: the shortest amount of time for muscular contraction to achieve either a specific force level or a maximum force of muscular contraction; equal to the greatest value achieved, during a defined muscular contraction, the quantity change in force divided by chance in time
- **Maximum strength**: the greatest amount of muscular force that can be voluntarily generated against an external resistance, normally measured by a 1 RM, where both eccentric and concentric contractions occur

- **Muscle excitability**: a fundamental characteristic of muscle, the ability to respond to stimuli either electrical or nerve impulses
- **Muscular endurance**: the ability to persist in physical activity or resist muscular fatigue, measured by time of muscular contraction or distance through which muscular force is applied
- **Muscular strength**: the contractile force generated in a muscle or group of muscles
- **Peak torque**: the greatest muscular torque that can be generated at a designated joint under defined conditions (e.g., defined angular velocity)
- **Plyometrics:** exercises in which concentric muscle action is immediately preceded by eccentric loading of the muscle (e.g., foot plant followed by lift off in the long jump, rebounding in basketball)
- **Rebound motion**: movement where the muscle is suddenly preloaded and forced to stretch an instant prior to its concentric action; an example is jumping down from a bench to a surface and immediately springing back up
- **Repetition (rep):** each count of each cycle of an exercise that is performed; series of repetitions called "sets" are performed on each exercise in a training program
- **Resistance training**: all types of "strength" or "weight" training exercises that use weight or resistance to build strength and muscle mass, this may involve free weights, isokinetic dynamometers, variable resistance machines, body weight, and isometric contractions

- **RM**: acronym for "repetition maximum" (e.g., 5 RM stands for the maximum amount of weight for which no more than five repetitions of a specified exercise can be performed by the exerciser
- **Running economy**: sub-maximal oxygen uptake per unit of body weight (i.e., the less oxygen needed per weight at a certain pace; the less energy used, the more economical the runner)
- **Set**: a designated number of repetitions of an exercise movement done consecutively without rest
- **Specificity of training**: theory that purports the body adapts to the training stimuli it is required to deal with; following training the body is likely to perform best at the specific speed, type of contraction, muscle group usage, and energy source usage it has become accustomed to in training
- **Station**: a spot or place where a specific exercise is performed, this could be the location of a certain piece of strength training equipment which a person is appointed to perform; typically multiple stations are included in a circuit training program
- **Strength curve**: a graph of the maximum amount of muscular tension achievable throughout the range of motion during a movement
- **Super slow training**: typically represents 4-6 repetitions consisting of a 10-second concentric phase followed by a four-second eccentric phase
- **Traditional training**: originally the standard Nautilus training protocol, 8-12 repetitions are performed, each composed of a two-second concentric action, a one-second pause, followed by a four-second eccentric action

- **Transfer of training**: attempting to enhance an ability with non-specific training; belief that many of the activities engaged in during weight training develop and increase performance capabilities as they relate to other functions
- **Variable resistance**: strength training equipment in which the amount of resistance required to perform an exercise approximates the strength curve through the use of elliptical cams or other such technology (e.g., dual cams)
- **Volume**: the amount of weight lifted multiplied by the number of repetitions per set times the number of sets executed

CHAPTER 2

REVIEW OF LITERATURE

Hormonal Effects of Resistance Training

Hormonal Effects Related to Load

While this study does not directly examine the hormonal effect of resistance training, the research in this area should be examined to ensure that a design flaw does not exist in this study due to what is happening at the hormonal level.

Hakkinen and Pakarinen (1993) found that a single bout with sub-maximal loads (70% of maximum) yielded statistically significant increases in concentrations of serum total and free testosterone ($p \leq 0.05$), cortisol ($p < 0.001$), and growth hormone (GH); whereas, corresponding changes with a single bout of maximal loads were statistically insignificant, except for a relatively slight increase in serum GH level. This contradicts Raastad, Bjoro, and Hallen (2000) who, when analyzing testosterone, luteinizing hormone, follicle stimulating hormone, cortisol, adrenocorticotropic hormone, growth hormone, insulin-like growth factor, insulin, sex hormone binding globulin, creatine kinase, total protein, glucose, and lactate, found that the responses of testosterone and cortisol were greater during the high-intensity protocol (100% of 3RM squat and 6RM leg extensions) as compared to the moderate-intensity protocol (70% of 3RM squat and 6RM leg extensions). This study examined lifts in which the participants performed at 80% or 35% of 1 RM.

Further research suggests that by manipulating both load and frequency, the hormonal effects of resistance training, due to load, will not be a confounding variable in the study. Vanhelder, Radomski, and Goode (1984) found that with weightlifting exercises of equal total external work output and duration, as well as identical work-rest intervals, the load (85% versus 28% of 1 RM) and/or frequency (not manipulated) of an exercise are determinant factors in the regulation of plasma GH levels. However, Schwab et al. (1993) found that moderate weightlifting (90-95% of 6 RM) and light weightlifting (60-65% of 6 RM) have similar results on concentrations of serum testosterone in males. It, therefore, can be concluded that neither maximum nor light loads produce a hormonal change nor do light loads at the same rate as heavier loads. However, a range of sub-maximal loads does affect hormonal response and it is unknown what effect the frequency of an exercise will have on hormonal response. So there is a potential confounding variable that will not be measured (i.e., the hormonal effects of resistance training due to load) which may be used to explain the outcome of this study.

Hormonal Effects Related to Age and Gender

This study used school age participants (ages 14-16 years) who were expected to have a wide range of physical maturation ages. This study used both males and females who by biological definition are hormonally different. What does the research tell us about how age, in general, will affect the hormonal response to weight training? Hakkinen and Pakarinen (1995) looked at the hormonal responses to resistance exercise in men and women at different ages (30's, 50's and 70's) and found that the females and elderly males (age ≥70 years) did not have a change in mean concentrations of serum testosterone, but all males ≤50 years did. Serum growth hormone increased in both genders in the groups ≤50 years of age but not in the older groups. Kraemer et al. (1998) did a similar study using men. They looked at total and free testosterone, adrenocorticotropic hormone, cortisol, growth hormone, and insulin. The younger (≤30 years old) and older (≥62 years old) men both saw increases in total and free testosterone, adrenocorticotropic hormone, and cortisol. However, analysis shows that the younger group has a significantly higher magnitude of increase for total and free testosterone, adrenocorticotropic hormone, and growth hormone. Kraemer et al. (1991) examined changes in whole blood lactate and serum glucose, human growth hormone, testosterone, and somatomedin-C in both males (24.7 ± 4.5 years) and females (23.1 ± 3.3 years). Males showed a greater change in testosterone than females and, for females, the only significant increase in growth hormone occur after doing a 10 RM load with 1-minute rest periods, as opposed to a 5 RM load with 3-minute rest periods.

The problem with comparing these studies to the current study is that the age groups differ. Past research studies used only adults and the current study used adolescents. Kraemer et al. (1992) looked at resistance exercise-induced increases in serum testosterone in adolescent males using junior elite male Olympic-style weightlifters. It was found that exercise elicited significant ($p \leq 0.05$) increases in serum testosterone, cortisol, growth hormone, plasma beta-endorphin, and whole blood lactate. Subsequent analysis revealed that participants with more than 2 years training experience exhibited significant exercise-induced increases in serum testosterone from pre-exercise to five minutes post-exercise (16.2 ± 6.2 to 21.4 ± 7.9 nmol per l), while those with 2 or less years of training showed no significant serum testosterone differences. None of the other hormones or whole blood lactate appeared to be influenced by training experience. Staron et al. (1994) reported that skeletal muscle adaptations, that may contribute to strength gains of the lower extremity, are similar for men (age 23.5 ±3.2 years) and women (age 20.6 ±1.5 years) during the early phase of resistance training and that they occurred gradually.

Lastly, in the study that relates the most to the current study with respect to age and gender of population, Tsolakis et al. (2000) found that pre-pubertal (11-13 years) and pubertal (14-16 years) groups respond differently from one another, both anabolicly and androgenicly to strength training, but the same within each group. This means that the participants in the study by Tsolakis et al. that are pre-pubertal may respond differently to the training then will participants who are post-pubertal. It is unknown how participants in the current study will respond hormonally; but, due to the similarity in age and Tanner stage of the participants, the author does not expect it to effect the outcome.

Prior research has shown that hormonal response could confound the results in the current study. Date of birth (age) data was recorded. Although it is not a variable that was used to test the current study's hypotheses. However, it could be used in future data analysis to explain the results of this study. It is expected that the random assignment of participants to groups prevented pubertal level from affecting the results of this study.

Resistance Training and Its Effect on the Force-Velocity Curve

Because the current study examined training at different points on the force curve and also how training affects the force curve as a whole, other research on the force curve was also examined. Kramer and Newton (1994) reported that a combination of light load and fast weight training repetitions is best for improving maximum rate of force development, high velocity force production, and maximum mechanical power. In contrast, they state that training with heavy load is only best for improving maximum strength as it is less effective in improving maximum rate of force development, high velocity force production, and maximum mechanical power. Cronin, McNair, and Marshall (2001a) found that the combinations of load, movement, and contraction type affects mean and peak power in different capacities. Mean power output for rebound motion was 11.7% greater than concentric only motion. The effect of the rebound was to produce greater peak accelerations (average 38.5% greater), greater initial force and peak forces (average 14.1% greater), and early termination of the concentric phase. Finally, they found that loads of 50-70% 1 RM maximizes mean and peak power. Apor (1987), in a study on the force-velocity relationship, suggested that strength training with 30% of maximum force increases the maximum power the most and that high load strength training causes changes primarily in the high force end of the curve. This implies that the whole curve is not changed and that just specific parts of the curve are altered. Bell and Wenger (1992) found that maximum force is inversely related to the velocity of shortening; in other words, the faster one moves, the less force one can produce or to produce the greatest amount of force one must move slowly against a heavy resistance. However, they do not suggest a particular force or speed value for optimal training when trying to increase maximum force or velocity.

Cronin, McNair, and Marshall (2001b) found in pre-training and post-training testing that the training velocity associated with the strength-trained (80% 1 RM) group produced significantly greater improvement in mean volume of weight lifted (85kg) and mean power output (13.25 W) as compared to the power (60% 1 RM) and control groups ($p < 0.05$). The strength-trained and power-trained groups significantly improved netball throw velocity by 12.4% and 8.8%, respectively, but with no significant difference between the groups. The validity of velocity-specific training and subsequent adaptations to improve functional sporting performance appears highly questionable as there was not a statistically significantly difference between the groups. The power group which trained at a faster rate, closer to the throw velocity, experienced a smaller percentage change. Keeler et al. (2001) found, when comparing strength gains in over eight different exercises, that traditional training was better (correlated with greater strength gains) than super slow training for sedentary individuals. Young, McDowell, and Scarlett (2001) found that straight sprint training and agility training are specific to themselves and produce limited, if any, transfer to each other.

Jones et al. (2001) conducted a study that is probably the most similar to the current study with respect to training load and velocities. They had a light weight training group (40-60% 1 RM) and a heavy weight training group (70-90% 1 RM) where the participants lifted as fast as possible during the concentric contraction phase of each repetition. While no statistically significant interaction was found between load and peak power, peak velocity, and 1 RM, trends showed light loads lead to increased peak power and peak velocity and the heavier loads improved 1 RM the most. Enoka (1988) stated

> "Based on a substantial review of the literature, McDonough and Davies (1984) concluded that an increase in strength with voluntary training techniques requires loads that are at least 66% of maximum."

Enoka also noted that strength training results in increased strength, but no change in peak power production. Since power is the product of force and velocity and training causes increases in force, then, according to Enoka's conclusions about peak power, strength training must elicit a decrease in the maximum velocity of whole muscle shortening. More likely the point on the force-velocity curve the peak power occurs does not change and force amount use to achieve peak velocity becomes a smaller percentage of a participant's 1 RM.

Schmidtbleicher and Haralambie (1981) had one group train with few repetitions and maximum loads, and a second group with more repetitions and smaller loads. Both groups lifted the same total volume during each training period. Muscle excitability (contraction time of response to electrical impulse) significantly decreased in all types of training. Schmidtbleicher and Haralambie concluded that strength training with maximum loads involved training the fast muscle fibers, whereas, when training with more repetitions, the training influence is less marked, and affects both fast and slow fiber types.

One measure that separates the current study from all prior studies is that training was monitored for ten participants to ensure that the participants were training in the assigned method. Although many studies are similar to the current study, the present study differs in that, to date, no weight training study has monitored the various kinematic values of participants over an extended period of training. This was a valuable tool in explaining the results of the current study as well as the timelines of any changes.

Specificity of Strength Training

Specificity and Isokinetic Training

The current study examined training at high force and high velocity points on the force-velocity curve and attempted to determine how training protocol affects the force curve as a whole. If no effect occurs on the whole curve, then this is really a study of specific of training (i.e., training on the high force end of the curve only alters the high force end of the curve and training on the high velocity portion of the curve would only alter the high velocity part). Some studies have looked at velocity specific of training. However, most of these studies have used isokinetic devices. This information is examined, but one of the reasons this study was conducted was to look at the effects of isotonic training, which is the method most commonly used.

One of the first studies looking at velocity specificity and isokinetic training was conducted by Moffroid and Whipple (1970), who found that velocity of exercise is specific for muscular endurance (i.e., endurance gains occur at the velocity of endurance training) and that force and/or peak torque increases at or below training velocity. Lesmes et al. (1978) also found that isokinetic training at various speeds increases endurance, work output, and peak muscle torque. Lesmes et al. could not compare between velocities because of the cross training effect between legs (i.e., participants trained each legs with a different training protocol). However, velocity specificity has not always been shown. Caiozzo, Perrine, and Edgerton (1981) found transfer to all but one other speed when participants trained at the lowest speed. When training at the higher speed, they found transfer to other velocities as well. Ewing et al. (1990) had mixed results depending on the variable (peak torque, power, muscle fiber type, fiber cross sectional area), but power for all training speeds improved. Ewing et al. found no significant changes in percentages of type I, IIa and IIb muscle fibers; but when training at either speed, participants showed significant increases in the number of type I and IIa fibers. Kanehsia and Mitusmasa (1983) used slow, fast, and intermediate speed-training groups. The slow group showed a significant increase in power at all speeds. The intermediate group showed a significant increase in power at four of the five speeds. The fast group showed increases in power only at the fastest speed. Coyle et al. (1981) using slow, fast, and mixed speed groups only found speed specific improvements in peak torque with the slow group. Whereas, the other groups had improvements in peak torque at all speeds.

Prevost, Arnold, and Maraj (1999) had participants train on an isokinetic device two days at three different speeds. Participants that trained at the higher speed were the only ones that had changes in mean peak torque and then only at the highest speed. These changes were similar to changes found in other studies lasting six to ten weeks. They, therefore, surmised that training at high velocity does not cause hypotrophy, and all changes are due to neural adaptations. It is widely accepted that more than two sessions of strength training are required to cause hypotrophy and that changes in 1 RM the first six weeks of weight training are due to neural changes. Smith and Melton (1981) divided participants into four training groups: control, isotonic resistance, slow isokinetic, and fast isokinetic. At the end of six weeks of training, all exercise groups showed an increase in all types of strength (isometric, isotonic, and isokinetic).

These studies have shown a mixture of results. What this means or why it is occurring is not clear. It appears that some level of specificity exists; but, there is also a great deal of transfer (i.e., changes at velocities other than the one being trained). All that can be concluded is that further research needs to be conducted on the specificity of velocity of training and mechanisms that cause the results of these studies.

Specificity and Isometric Training

It was not the intention of this study to explore isometric training or concentric movements at the high force end of the force-velocity curve which are very close to being isometric due to the very slow velocity. It did study training at different parts of the force-velocity curve in an attempt to determine if training on those parts of the curve produced results specific to the training.

Specificity of training relates to all types of training. Therefore, isometric training and the specificity of isometric training will be reviewed here. Duchateau and Hainaut (1984) found that isometric and isotonic training have different effects on the mechanical properties (e.g., maximum tetanic tension, peak rate of tension development, twitch force, rate of twitch force development, relaxation, maximum shortening velocity, and maximum muscle power) of muscle. These findings support the contention that specificity of training is related to the type of contraction, but it does not indicate any specificity due to speed of movement, assuming movement occurs. Hakkinen, Komi, and Alen (1985) found that high power training improves isometric contraction force. They felt this was due to muscle hypertrophy and that the neural adaptations were velocity specific. From this research it can be concluded that there is a chance that resistance training is contraction specific. However, all measures in the current study used concentric and eccentric contractions so that the type of contraction did not affect the outcome of the study.

Specificity, Contrast, and Transfer of Training

The goal of the current study was to compare two different types of training and to try to determine if one type is better than the other for improving strength and power. It is acknowledged that a combination of the two types of training may be the most beneficial, but that was not explored.

Duthie, Young, and Aitken (2002) looked at training power using various training methods. They found that the contrast method of training (alternating high force and high velocity training) was best for increasing strength, as measured by 1 RM, and increasing power, as measured by peak power and jump height using a force plate, but only for athletes that already had relatively high strength levels. These results appear to contradict training specificity and, in doing so, also raise the question of which training group in the current study has the greatest changes in power. Harris et al. (2000) found that contrast or combination training has better transfer to other measures of strength and power (i.e., various 1 RM's, jumping, power, and velocity tests) than training solely with high force or high power. This contradicts Behm and Sale (1993), who found velocity specificity in resistance training (i.e., that the greatest strength gains occur at or near the training velocity). The contradiction might be explained by Behm and Sale (1993b) themselves, who when they had participants try to move very fast when a high force was required, found evidence that the intent to make a high-speed contraction may be the most crucial factor in velocity specificity. Participants were instructed to try move as fast as possible, but the force required did not permit them to move at a fast rate. Westcott (1993), looking solely at the parameter of strength, found that speed of movement has no significant effect on strength gains.

Wilson et al. (1993) found that high power training is better than training with higher force or plyometrics for increasing jumping height and isometric strength. This contradicts Newton and McEvoy (1994), who found that heavy weight training leads to the greatest increase in strength and throwing velocity. Bloomfield et al. (1990) found no increase in throwing velocity after eight weeks of strength training. Behm's (1991) results disagree with the findings of the three previously mentioned studies and reported that the three different types of training are equally effective in promoting strength gains. This agrees with Young and Bilby (1993), who found that high speed and slow controlled movements produced increases in strength, power measures, and muscle hypertrophy. Paavolainen et al. (1999) found that explosive (high power) training improves running economy and muscle power in distance runners, but they did not compare different types of training. Various opinions still exist as to which type of training is best or even if a combination of two types of training may be the best for increasing strength and power. Due to the mixed results to date, it is clear that more research, such as the current study, needs to focus on the difference of high velocity versus high power strength training.

Table 1: Summary of Studies on Contrast Training

Author(s)	Results
Duthie, Young, and Aitken (2002)	Contrast training best for power and strength
Harris et al. (2000)	Contrast training best for other measures of jumping, power, and speed
Behm and Sale (1993)	Strength gains found near training velocity
Behm and Sale (1993b)	Intention to move fast most important for velocity specificity
Westcott (1993)	Speed trained at not important for strength gains
Wilson et al. (1993)	High power training is better for increasing jump height
Newton and McEvoy (1994)	High force training better for increasing throwing velocity and strength
Bloomfield et al. (1990)	No increase in throwing velocity with weight training
Behm (1991)	All types of strength training are equally effective
Young and Bilby (1993)	All types of strength training are effective
Paavolainen et al. (1999)	High Power training improves running economy

Specificity and Neural Adaptations

Changes in strength are predominantly attributed to hypertrophy and neural adaptations. Neural adaptations are difficult to measure. Yet, neural adaptation may be used to explain the results of strength training studies. Measures that have been used to evaluate changes in neural adaptations include electromyography and nerve conduction velocity. Studies, in which neural adaptations are used to explain results of strength training, as they relate to the current study, are reported here. Sale (1988) determined that most adaptations due to strength training are neural and this accounts for much of the specificity that is found in the literature. He found that strength training may cause adaptive changes within the nervous system and this allows a trainee to more fully activate prime movers in specific movements and to better coordinate the activation of all relevant muscles, thereby affecting a greater net force in the intended direction of movement. Sale also found an influence on one limb when only the opposite limb was trained (i.e., even though only the right leg was strength trained, the left leg show strength gains; cross training effect). Research also shows specificity of training that provides further evidence of neural adaptations. If Sale is correct, the current study could be very valuable because the kinetic values measured may be the results of these neural adaptations. Young (1993) believes that high power training is better for the development of inter-muscular coordination, which would transfer more to other activities. But, Young also believes that high force training is better for intra-muscular coordination development and fast twitch muscle fiber hypertrophy. At this point, the findings of neural adaptations are hypotheses, requiring further testing, and the current study tests some of these hypotheses.

Single Versus Multiple Sets

The current study had participants perform a single set of repetitions. Some of the results of prior studies are mixed when comparing strength gains associated with looking at single versus multiple sets. For example, Schlumberger, Stec, and Schmidtbleicher

(2001) found that, for women, multiple set training (i.e., three sets) produces superior results for increasing 1 RM when compared with single set training. However, they found, for individual exercises, that data was mixed as both groups made significant improvement on leg extension, but not on seated bench press. Most of the research shows that single sets are just as effective as multiple sets. Carpinelli and Otto (1998) and Carpinelli (1997) found that most of the studies reporting the results of training with single versus multiple sets do not substantiate the tenet that multiple sets are better. In fact, the preponderance of evidence suggests, that for training durations of four to 25 weeks, no significant differences were found in the increase in strength or hypertrophy as a result of training with single versus multiple sets. Carpinelli and Otto also found little scientific evidence, and no theoretical or physiological basis, to suggest that a greater volume or number of sets of exercises elicits greater increases in strength or hypertrophy. Westcott (1991) found no significant differences in muscular strength or endurance gains among groups that train with one set of 10-repetitions or one set of 20-repetitions. Paulsen, Myklestad, and Raastad (2003) also found that using a single set is just as effective for upper body training. This is of interest as the current study used upper body training. The current literature supports that single set weight training is just as effective as multiple set weight training. Therefore, the results of the current study should be applicable to people who weight train with single or multiple sets.

Using 1 RM as a Measure of Strength

This study used a 1 RM test as a measure of strength with one-minute rest intervals between repeated attempts of 1 RM. The literature was searched to determine if this is a valid measure of maximum strength and all evidence indicates that it is. Fields, Bemben, and Mayhew (1997) used 1 RM bench press and leg press to measure lower and upper body strength. This measure is described as a standard protocol by Stone and O'Bryant (1984) and Stone, O'Bryant, and Garhammer (1981). Matuszak et al. (2003) found that one-minute rest intervals are sufficient for recovery between attempted lifts during 1 RM testing. No literature was found that suggests that 1 RM is an invalid measure for strength. Therefore, for the purposes of this study it is assumed to be valid.

CHAPTER 3

METHODS

Participant Population

Participants in this study were 16 male and 15 female students in a high school freshman/sophomore physical education class. Data was collected during the fall semester, 2003. The mean age of the participants was 15 years 3 months (males-15 years 2 months and females-15 years 3 months). Participation in this study was completely voluntary and followed Michigan State University guidelines regarding informed consent. Appendix A contains a copy of the informed consent form that was used in this study.

The total number of participants that completed this study was 31. A total of 37 participants were tested at the beginning of the study. Six were dropped due to being injured in activities outside of the current study, moving to a different school, dropping the physical education class, or lacking sufficient attendance required for inclusion.

Participants were asked to do a self-evaluation of sexual maturation using Tanner stages. This is a valid method of assessing maturity (Duke, Iris, and Shasby, 1980) and has been used in other strength training studies involving adolescent participants (Lillegard et al. 1997). The mean Tanner stage for all participants was 4.54 ± 0.57 (females 4.40 ± 0.63, males 4.68 ± 0.47).

Anthropometrics

An electronic scale with increments to the nearest tenth of kilogram was used for all measures of participant weight. A standing anthropometer with increments to the nearest millimeter was used to measure standing height. An anthropometer with increments to the nearest millimeter was use to measure arm length. Lastly, a steel tape with increments to the nearest millimeter was used to measure arm girth. The data collected was expected to be accurate except for human (test administrator) error and any undetectable equipment inaccuracies. In an attempt to eliminated measurement error, all measures where taken twice, and any pair of measures more than two units (millimeters or tenth of a kilogram) different precipitated more measures until the consistent difference was two units or less. The tester was experienced with the equipment used, having worked with this instrumentation in various setting for the past ten years. Due to the author's prior experience with the equipment, reliability of the data collection procedures was not considered to be a factor to adversely affect the accuracy of data collected in this study.

Treatment

Each participant was randomly assigned to one of two treatment groups and trained twice a week. The population was believed to be homogenous with respect to the effect of the treatment based on similarities in Tanner stage and age. Therefore, it was not believed that assignment to a specific group on the basis of these parameters (Tanner stage, age, height, weight, or prior sports involvement) was warranted. The two treatment groups were named the high velocity group and high force group. The treatment period was for 15 weeks. An approximately equal number of participants of each gender was placed in each treatment group (seven females and eight males in high velocity, eight females and eight males in high force). All training sessions were monitored to ensure that the participants trained according to the assigned method (i.e., proper weight, number of repetitions, and assigned frequency). In addition, ten of the participants (five from each group; two females and three males in high velocity, three females and two males in high

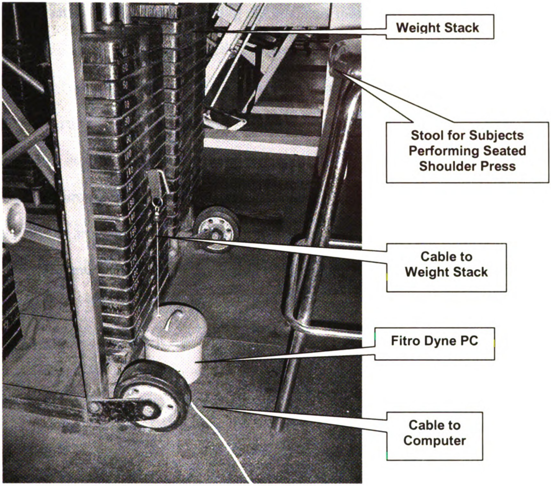


Figure 2. Fitro Dyne PC Attached to Weight Stack of Universal Machine

force) had all of their training sessions electronically monitored using the Fitro Dyne PC (see Figure 2) to ensure that they trained according to the assigned method and as a check to support the likelihood that all participants were able to follow their training instructions. In addition, data collected during the monitored training sessions could be used to help explain the history of changes that occur due to training and in between testing.

Weight lifted in conjunction with the velocity of the weight being moved over time was collected with the Fitro Dyne PC for every training repetition for the ten participants whose training was being electronically monitored. The samples collected from the training sessions showed that each participant had been in compliance with the lift velocity requirements of this study. Also, the maximum magnitudes of the velocities for the participants in the high force group was less and did not fluctuate as much during the lifting and lowering phases of each repetition, whereas the velocity pattern for the high velocity group showed much greater variability in velocity. These results, in addition to observation of the participants training, made the author very confident that all participants complied with the lifting requirements.

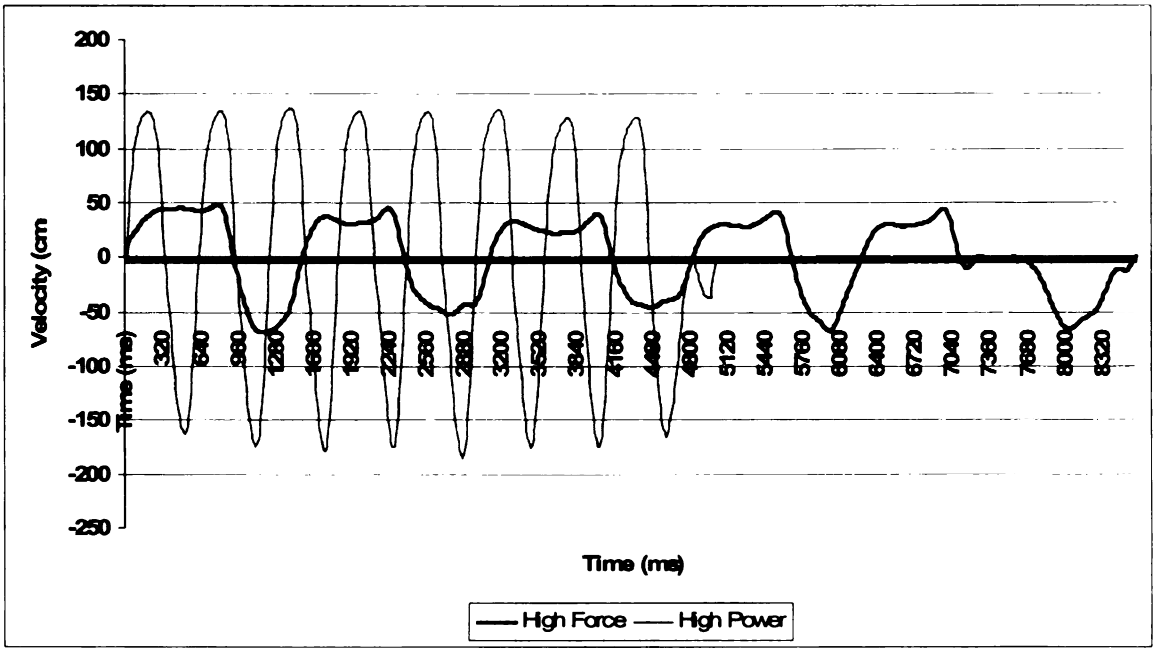


Figure 3. Typical Velocity Data Collected as Represented by Two Participants

Figure 3 shows typical velocity data for one participant in the high force group and one participant in the high velocity group. It is evident in this typical velocity curve for the high force group that the acceleration approximates zero during the middle of the lifting phase of each repetition, whereas acceleration is relatively large during the middle of the lifting phase for the high velocity group. In general, the acceleration magnitudes for the high velocity group are much higher.

Treatment for both groups was performed twice a week for 15 weeks, with the exception of week eight which was used for testing. During weeks one, eight, and fifteen, participants engaged in one training session and one testing session. The results gathered in the first and final weeks were the data used for analysis in this study. The testing session in week eight was used to adjust the 1 RM values for all participants, and the results were used to adjust their training weight for the remaining training sessions for 80% of the 1 RM and 35% of the 1 RM. This test at the midpoint of the study was not intended to be used for data analysis, but to adjust the values for the different percentages of 1 RM.

High Velocity Group

The high velocity group did one set of ten repetitions of the seated shoulder press using 35% of their last tested 1 RM with their maximum repetition frequency. Due to the fact that 35% of 1 RM is also the optimal percent of 1 RM for peak power, it is similar to high power groups in other studies (Apor, 1987). The high velocity group had 15 participants.

High Force Group

Participants in the high force group did one set using 80% of their 1 RM for the seated shoulder press, and attempted to complete up to ten repetitions. Frequency for repetition was self-selected by the participants in the high force group. While some participants may have choose to use their maximum repetition frequency, the greater load of the high force group prevented members of the high force from reaching velocities similar to participants in the high velocity group. The high force group had 16 participants.

Purpose of the Study

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

1. If participants trained two times per week over a 15 week period at a high velocity using lighter weight (i.e., 35% of 1 RM), can they increase the amount of force, as measured by 1 RM, as much as if they had trained at a high force (i.e., 80% of 1 RM)?
2. If participants trained two times per week over a 15 week period at a high force (i.e., 80% of 1 RM at a self-selected frequency of repetition), can they increase the peak velocity generated when lifting lighter weights (i.e., 35% of 1 RM) and the time to peak velocity as much as if they had trained at a lighter weight (i.e., 35% of 1 RM at a high frequency of repetition)?
3. If high school male and female participants trained two times per week over a 15 week period with the same protocol, does gender affect their ability to increase the amount of maximum force (1 RM), peak velocity generated when lifting lighter weights (i.e., 35% of 1 RM), and the time to peak velocity?
4. How do two different weight training programs (i.e., high frequency at 35% of 1 RM and high force associated with 80% of 1 RM at a self-selected frequency of repetition) affect biomechanical parameters (i.e., complete velocity pattern of the weight for all repetitions of weight taken every 10 milliseconds) over 15 weeks?

The answers to these research questions could greatly change the methods used to weight train athletes and other populations in the future.

Reliability of the Measures

A Fitro Dyne PC (see Appendix B) was used to input the data (weight (kg), time (ms), speed (cm/s), acceleration (m/s^2), force (N), power (W), distance (cm)) into a Toshiba Satellite Pro 490 CDT, Pentium Pro(r) 233 MHz processor with 32 megabytes of RAM. The Fitro Dyne PC has a resolution of 12 bits, range of ±600 cm/s, resolution motion speed of 0.29 cm/s, resolution distance of 5.4 mm, and sample frequency of 1 kHz. The data collected from the instrumentation was expected to be accurate to the nearest tenth of a unit. Exceptions to this accuracy could be the result of human (test administrator) error, calibration error, and any undetectable equipment inaccuracies. The testers were experienced with the equipment used. The Fitro Dyne PC that was used was calibrated to be accurate to ±5.4 mm. Due to the author's two years of prior experience with the equipment, reliability of the data collection procedures was not considered to be a factor to adversely affect the accuracy of data collected in this study. An example of the numerical data that can be generated by the Fitro Dyne PC is found in Appendix C. Figure 2 shows the Fitro Dyne PC setup used for this study.

Testing

Participants performed the seated shoulder press using a Universal machine following guidelines established by the National Strength and Conditioning Association (Appendix D). Figures 4-6 show the sequence of movements for the seated shoulder press. Participants were asked to achieve an elbow angle of less than 90°, at the end of the eccentric phase of movement by lowering the handles to shoulder level (see Figure 4, which shows the handles just above shoulder level). At the top of the movement, participants were instructed to lock out the elbow joints (see Figure 6).

The range of weights available for this exercise on the Universal machine was 15 to 200 pounds in increments of 2.5 pounds. Participants were tested at the beginning, middle, and end of the study for 1 RM and also for three repetitions of 35% of their 1 RM resistance, which they were instructed to perform as fast as possible. The test in the middle of the study was used to adjust the 1 RM and the related 35% of their 1 RM.

Figure 4. Starting to Raise the Weight

Figure 5. Weight Almost Fully Raised

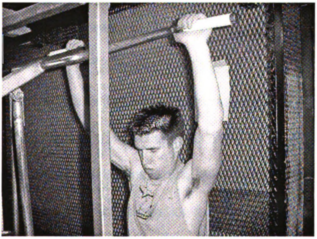


Figure 6. Elbows Almost Locked Out

The protocol used for assessing 1 RM required participants to warm up with five repetitions at 15 pounds. Participants would then guess their 1 RM and attempt that weight. On a successful attempt the weight was increased 2.5 pounds and then tried again after a five minute break. After a failed attempt, the weight was decreased 2.5 pounds and then tried again after a five minute break. Participants were given one attempt to repeat on a failure if they desired. Three to five attempts where typically necessary to determine 1 RM. Proper form was enforced, following guidelines in Appendix B.

Anthropometric and physical activity participation data were collected at the beginning and end of the study. A personal data sheet (see Appendix E) was used to collect and code information on sports involvement, anthropometry, and maturation of the participants. Appendix F includes the guidelines used to collect all of the anthropometric measurements. Five potential participants who engaged in other physical activities that were deemed to affect the results of this study (i.e., any sport that required weightlifting or use of the upper body to manipulate heavy objects) were not allowed to participate in this study. Of the five people excluded from the study, three played football, one golfed, and one worked on his family's farm.

Statistical Analysis

The variables selected for statistical analyses are reported in Table 2. The Pearson Product Moment linear coefficient of correlation and analysis of variance (ANOVA) were applied in an attempt to find significant relationships and correlations between the selected variables. A 0.05 alpha level of significance was used for all measures. Statistical Product and Service Solutions version 11.5 software, formerly Statistical Package for the Social Sciences (SPSS) was used to calculate all statistical measures.

Table 2: List of Variables Used in Statistical Analyses

Collected Variables
Weight*
Height*
Maturational Stage*
Arm Girth*
Arm Skin fold*
Arm Length*
Weight Lifted for 1 RM*
Time to Maximum Velocity at 35% of 1 RM*
Maximum Velocity at 35% of 1 RM*
Training Group
Gender

*Pre and post test values used.

Statement of Each Hypothesis

Hypothesis Based on Group Comparisons

1. No difference will be found between the high velocity and high force groups from pre-test to post-test in the change of 1 RM, change in maximum velocity when lifting 35% of 1 RM., or change in time to maximum velocity when lifting 35% of 1 RM. Significance was determined by a repeated measures design one-way ANOVA. The factor (training group), with two levels (high force and high velocity), between subjects, and the significance of their interaction were tested multivariately. The two level within subjects factor (pre-test and post-test) was tested with a univariate F-test.

Hypothesis Based on Gender Comparisons

2. No differences between genders will be found from pre-test to post-test in 1 RM, maximum velocity when lifting 35% of 1 RM, or time to maximum velocity when

lifting 35% of 1 RM. Significance was determined by three repeated measures design one-way ANOVAs. The factor (gender), with two levels (male and female), between subjects, and the significance of their interaction, were tested multivariately. The two level within subjects factor (pre-test and post-test) was tested with a univariate F-test.

Regression Hypothesis

3. The variables of gender, weight, height, maturational state, arm girth, arm skin fold, and arm length will not be predictors of the dependent variables (1 RM, maximum velocity, and time to maximum velocity when lifting 35% of 1 RM). A stepwise regression was performed for each of these dependent variables using the independent variables of gender, weight, height, maturational state, arm girth, arm skin fold, and arm length as predictors.

Contamination of the Variables Being Studied

For purposes of this study, this investigator chose to use the shoulder press since none of the other weight training movements that the participants would be doing in the weight room in their physical education class would involve shoulder abduction and elbow extension, involving the deltoid and tricep muscle groups (Westcott, 1996). It is possible that other activities, in which the participants engage, could have interfered with the results of this study, but unless they had access to another weight room, it is highly unlikely that the activities involved resistance training. Due to this possible contamination of data, prior to each training session, participants were asked to fill out an activity log detailing any athletic or work related activities in the days since their last treatment session. All of this information was kept on file. It was also explained to the participants how other activities could alter the results of the study, and the importance of them being accurate in their activity logs. The data collected in the activity log was not expected to affect the results of the study, but to help the investigator explain any confounding results. If activities involved the same muscles and movements, the data was examined and when it was inconsistent with other data from the same group, it was to be thrown out. However, this did not occur within this study. The activity log can be found in Appendix G.

CHAPTER 4

RESULTS

The variables used for participant description and statistical analyses are shown in Tables 3-7. Table 3 contains variables for the entire population, Table 4 contains variables by gender, Table 5 contains variables by group, and Tables 6 and 7 contain variables by group and gender. Means and standard deviations were reported when applicable.

Table 3: Population Variables with Means and Standard Deviations

Variables (units)	Mean	Standard Deviation
1 RM Pre-test (lbs)	87.41	25.55
Peak Velocity Pre-test (cm/s)	163.65	16.94
Time to Peak Velocity Pre-test (ms)	365.49	136.48
1 RM Post-test (lbs)	98.87	29.37
Peak Velocity Post-test (cm/s)	174. 30	16.34
Time to Peak Velocity Post-test (ms)	411.61	71.09
Pre-test to Post-test Changes		
1 RM (lbs)	11.45	6.70
Peak Velocity (cm/s)	10.64	21.11
Time to Peak Velocity (ms)	46.13	126.03
Post-test Measures of Physical Characteristics		
Height (cm)	167.00	6.10
Weight (kg)	69.11	14.39
Tanner Stage	4.54	0.57
Arm Girth (cm)	29.97	3.44
Arm Length (cm)	69.21	3.54
Arm Skin fold (mm)	13.61	5.99

Table 4: Variables with Means and Standard Deviations by Gender

Gender	Female		Male	
n	15		16	
Variables (units)	Mean	Standard Deviation	Mean	Standard Deviation
1 RM Pre-test (lbs)	68.67	11.25	105.00	22.51
Peak Velocity Pre-test (cm/s)	158.69	12.88	168.31	19.27
Time to Peak Velocity Pre-test (ms)	400.67	117.62	332.50	148.12
1 RM Post-test (lbs)	75.67	11.63	120.63	23.59
Peak Velocity Post-test (cm/s)	164.67	14.21	183.33	12.89
Time to Peak Velocity Post-test (ms)	396.00	64.90	426.25	75.53
Change from Pre-test to Post-test				
1 RM (lbs)	7.00	4.93	15.63	5.44
Peak Velocity (cm/s)	5.98	17.43	15.01	23.79
Time to Peak Velocity (ms)	-4.67	89.43	93.75	138.94
Post-test Measures of Physical Characteristics				
Height (cm)	164.03	6.29	170.01	4.55
Weight (kg)	66.18	12.59	71.85	15.80
Tanner Stage	4.40	0.63	4.68	0.47
Arm Girth (cm)	28.69	3.28	31.17	3.24
Arm Length (cm)	67.07	3.64	71.22	1.96
Arm Skin fold (mm)	16.13	4.30	11.25	6.51

Table 5: Variables with Means and Standard Deviations by Group

Group	High Force		High Velocity	
n	16 (8 females,8 males)		15 (7 females,8 males)	
Variables (units)	Mean	Standard Deviation	Mean	Standard Deviation
1 RM Pre-test (lbs)	85.63	27.56	89.33	24.04
Peak Velocity Pre-test (cm/s)	159.31	14.29	168.29	18.74
Time to Peak Velocity Pre-test (ms)	384.38	123.66	345.33	150.61
1 RM Post-test (lbs)	96.56	30.15	101.33	29.37
Peak Velocity Post-test (cm/s)	168.98	17.85	179.97	12.83
Time to Peak Velocity Post-test (ms)	383.75	67.12	441.33	64.57
Change from Pre-test to Post-test				
1 RM (lbs)	10.94	5.84	12.00	7.75
Peak Velocity (cm/s)	9.67	21.69	11.68	21.19
Time to Peak Velocity (ms)	-0.63	84.65	96.00	145.59
Post-test Measures of Physical Characteristics				
Height (cm)	166.68	7.21	167.58	5.05
Weight (kg)	70.47	16.82	67.65	11.68
Tanner Stage	4.50	0.27	4.60	0.63
Arm Girth (cm)	30.94	3.64	28.93	2.99
Arm Length (cm)	68.96	4.05	69.47	3.02
Arm Skin fold (mm)	14.88	6.35	12.27	5.48

Table 6: Variables with Means and Standard Deviations for Males by Group

Group and Gender	High Force Males		High Velocity Males	
n	8		8	
Variables (units)	Mean	Standard Deviation	Mean	Standard Deviation
1 RM Pre-test (lbs)	105.00	25.50	105.00	22.04
Peak Velocity Pre-test (cm/s)	158.78	15.68	177.85	18.49
Time to Peak Velocity Pre-test (ms)	397.50	166.20	267.50	98.67
1 RM Post-test (lbs)	118.75	25.18	122.50	23.45
Peak Velocity Post-test (cm/s)	180.25	15.99	186.40	8.87
Time to Peak Velocity Post-test (ms)	397.50	76.86	455.00	66.55
Change from Pre-test to Post-test				
1 RM (lbs)	13.75	4.43	17.50	5.98
Peak Velocity (cm/s)	21.48	19.59	8.55	27.08
Time to Peak Velocity (ms)	0.00	99.43	187.50	106.73
Post-test Measures of Physical Characteristics				
Height (cm)	170.75	5.79	169.28	3.08
Weight (kg)	76.28	18.79	67.43	11.72
Tanner Stage	4.63	0.52	4.75	0.46
Arm Girth (cm)	32.14	3.39	30.20	2.97
Arm Length (cm)	71.16	2.52	71.28	1.36
Arm Skin fold (mm)	13.75	8.01	8.75	3.49

Table 7: Variables with Means and Standard Deviations for Females by Group

Group and Gender	High Force Females		High Velocity Females	
n	8		7	
Variables (units)	Mean	Standard Deviation	Mean	Standard Deviation
1 RM Pre-test (lbs)	66.25	13.02	71.42	9.00
Peak Velocity Pre-test (cm/s)	159.84	13.83	157.37	12.65
Time to Peak Velocity Pre-test (ms)	371.25	68.96	434.29	155.76
1 RM Post-test (lbs)	74.38	13.74	77.14	9.51
Peak Velocity Post-test (cm/s)	157.70	11.67	172.63	13.20
Time to Peak Velocity Post-test (ms)	370.00	57.67	425.71	63.47
Change from Pre-test to Post-test				
1 RM (lbs)	8.13	5.94	5.71	3.45
Peak Velocity (cm/s)	-2.14	17.48	15.26	12.82
Time to Peak Velocity (ms)	-1.25	73.96	-8.57	110.67
Post-test Measures of Physical Characteristics				
Height (cm)	162.61	6.32	165.64	6.34
Weight (kg)	64.66	13.27	67.91	12.56
Tanner Stage	4.38	0.52	4.43	0.79
Arm Girth (cm)	29.75	3.70	27.49	2.45
Arm Length (cm)	66.76	4.22	67.41	3.14
Arm Skin fold (mm)	16	4.40	16.29	4.54

Results for Each Hypothesis

1. No difference will be found between the high velocity and high force groups from pre-test to post-test in the change of 1 RM, change in maximum velocity when

lifting 35% of 1 RM., or change in time to maximum velocity when lifting 35% of 1 RM.

Significance was determined by repeated measures design one-way ANOVAs. The factor (training group), with two levels (high force and high velocity), between subjects, and the significance of their interaction were tested using multivariate analysis. The two time levels within subjects factor (pre-test and post-test) was tested with a univariate F-test. The results in Table 8 show no effect ($p > 0.05$) for the training group or the interaction of time and training group from pre-test to post-test on 1 RM based on the percent of 1 RM with which the participants trained.

Table 8: Results of Group by Time ANOVA on 1 RM

Effect	Df	F	p
Time (pre to post test)	1	87.439	.000
Training Group	1	0.188	.673
Time by Group	1	0.188	.668
Error	29		

A significant effect due to time indicated a difference in 1 RM from pre-test to post-test in each of the training groups (see Table 9). On average, the high force group gained 10.93 pounds and the high velocity group gained 12 pounds.

Table 9: Means and Standard Deviations by Group and Time on 1 RM

	High Force		High Velocity	
Variable (units)	Mean	Std Dev	Mean	Std Dev
1 RM Pre-test (lbs)	85.63*	27.56	89.33*	24.04
1 RM Post-test (lbs)	96.56*	30.15	101.33*	29.36

* The change from pre to post test is significant at $p < 0.05$.

In this case the hypothesis held, and participants from both groups had a significant increase ($p \leq 0.05$) from pre-test to post-test, but between the two different training groups (see Table 10) the difference was not significant ($p > 0.05$).

Table 10: Means and Standard Deviations by Group on Force

	High Force		High Velocity	
Variables (units)	Mean	Std Dev	Mean	Std Dev
Average Force (N)	323.74	110.98	166.76	55.50
Average Peak Force (N)	732.15	275.84	616.55	149.69

The results in Table 11 show an effect ($p \leq 0.05$) for the training group from pre-test to post-test in peak velocity based on the percent 1 RM with which the participants trained.

Table 11: Results of Group by Time ANOVA on Peak Velocity

Effect	Df	F	p
Time	1	7.667	.010
Training Group	1	5.345	.028
Time by Group	1	0.068	.796
Error	29		

A significant effect ($p \leq 0.05$) due to time indicates a difference from pre-test to post-test. Table 12 shows that both groups improved their peak velocity by over 10% in lifting 35% of 1 RM. On average, the high force group gained 9.68 cm/s and the high velocity group gained 11.68 cm/s.

Table 12: Means and Standard Deviations by Group and Time on Peak Velocity

	High Force		High Velocity	
Variables (units)	Mean	Std Dev	Mean	Std Dev
1 Peak Velocity Pre-test (cm/s)	159.30*	14.29	168.29*	18.74
1 Peak Velocity Post-test (cm/s)	168.98*	17.85	179.97*	12.83

* The change from pre to post test is significant at $p < 0.05$.

Despite a significant effect for training group showing up, an examination of the data shows that the hypothesis will still hold. When looking at the pre-test and post-test values for both groups, it is clear that while the change from pre-test to post-test is very much the same, the starting values for each group are not. Participants from both groups had a significant increase in peak velocity from pre-test to post-test, with only a 2.00 cm/s difference between the two training groups. But, the starting point for the high velocity group was 8.99 cm/s high than the high force group. The significant effect being found is due to the differences in the groups before training, and not due to different findings as a result of training.

The results in Table 13 show no effect ($p > 0.05$) for training group in time to peak velocity based on the force level with which the participants trained. A significant effect ($p \leq 0.05$) due to time indicates a difference from pre-test to post-test. There is also a significant effect ($p \leq 0.05$) due to the interaction of time and training group.

Table 13: Results of Group by Time ANOVA on Time to Peak Velocity

Effect	Df	F	p
Time	1	5.052	.032
Training Group	1	.082	.777
Time by Group	1	5.185	.030
Error	29		

From Table 14 and Figure 7 it is evident that the group that trained with the heavier load generally did not change their time to peak velocity, but time to peak velocity actually increased significantly for the high velocity group. In this case the hypothesis did not hold. Only participants from the high velocity group had a significant increase from pre-test to post-test in time to peak velocity and therefore the groups are adapting differently to the training.

Table 14: Means and Standard Deviations by Group and Time on Time to Peak Velocity

	High Force		High Velocity	
Variables (units)	Mean	Std Dev	Mean	Std Dev
Time to Peak Velocity Pre-test (ms)	384.38*	123.66	345.33*	150.61
Time to Peak Velocity Post-test (ms)	383.75*	67.12	441.33*	64.57

* The change from pre to post test is significant at $p < 0.05$.

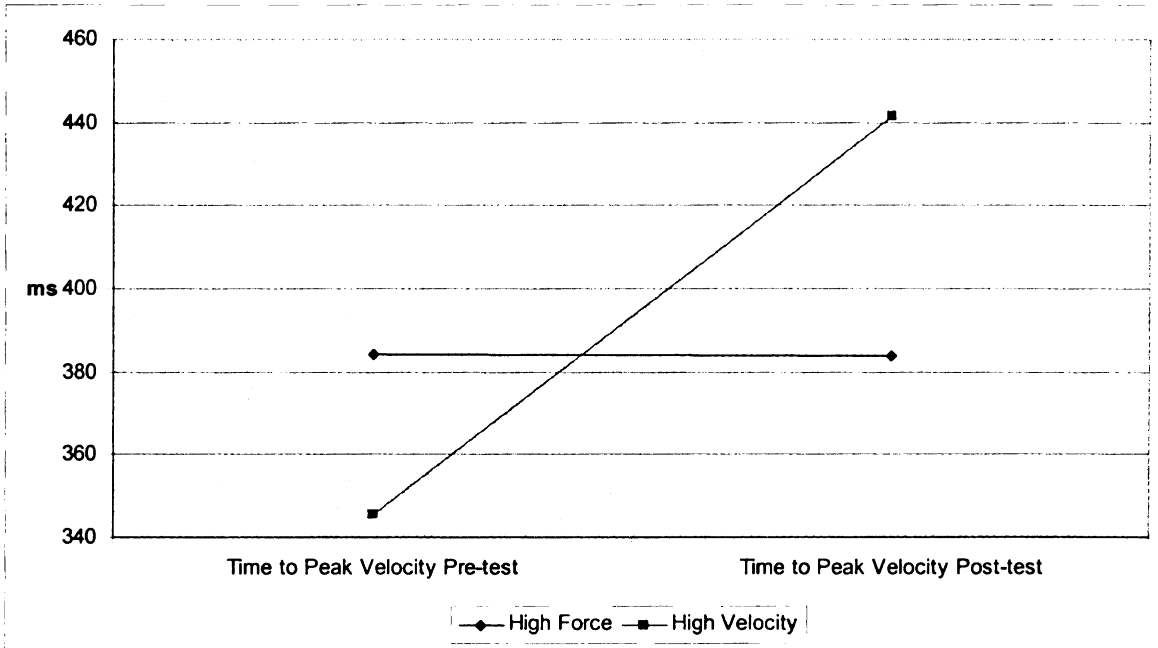


Figure 7. Plot of Means by Group and Time on Time to Peak Velocity

2. No differences between genders will be found from pre-test to post-test in 1 RM, maximum velocity when lifting 35% of 1 RM, or time to maximum velocity when lifting 35% of 1 RM.

Significance was determined by three one-way ANOVAs with repeated measures design. The factor (gender), with two levels (male and female), between subjects, and the significance of their interaction, were tested multivariately. The two level within subjects factor (pre-test and post-test) was tested with a univariate F-test.

As seen in Table 15, this hypothesis holds for time to peak velocity, but does not hold for 1 RM and peak velocity. Gender affects changed from pre-test to post-test in 1 RM and peak velocity, but not in time to peak velocity.

Table 15: Results for Gender from the Gender by Time ANOVAs

Variable	DF	F	p
1 RM	1	38.600	.000
Peak Velocity	1	13.132	.001
Time to Peak Velocity	1	0.346	.561
Error	29		

The data in Table 16 indicates that while both genders increased their 1 RM and peak velocity from pre-test to post-test, on average, males increased their time to peak velocity while females decreased their time. The difference in results for time to peak velocity was not found to be statistically significant as shown in table 15.

Table 16: Means and Standard Deviations by Gender and Time

	Males		Females	
Variables (units)	Mean	Std Dev	Mean	Std Dev
1 RM Pre-test (lbs)	105.00	22.51	68.67	11.25
1 RM Post-test (lbs)	120.63	23.58	75.67	11.63
Peak Velocity Pre-test (cm/s)	168.31	19.27	158.67	12.88
Peak Velocity Post-test (cm/s)	183.33	12.89	164.67	14.22
Time to Peak Velocity Pre-test (ms)	332.50	148.12	400.67	117.62
Time to Peak Velocity Post-test (ms)	426.25	75.53	396.00	64.89

Both genders had a significant change from pre-test to post-test in 1 RM, maximum velocity when lifting 35% of 1 RM, and time to maximum velocity when lifting 35% of 1 RM. This is expected as both groups also had a significant effect for time from pre-test to post-test on the same measures. These results are shown in Table 17.

Table 17: Results for Time from the Gender by Time ANOVAs

Variable	DF	F	p
1 RM	1	146.638	.000
Peak Velocity	1	7.762	.009
Time to Peak Velocity	1	4.437	.044
Error	29		

Only 1 RM was found to have a significant ($p \leq 0.05$) interaction for gender by time ($F(1, 29) = 21.310$, $p = 0.000$). This is shown graphically in Figure 8. It is clear the slopes of the lines are different and males have a greater rate of change in 1 RM than females.

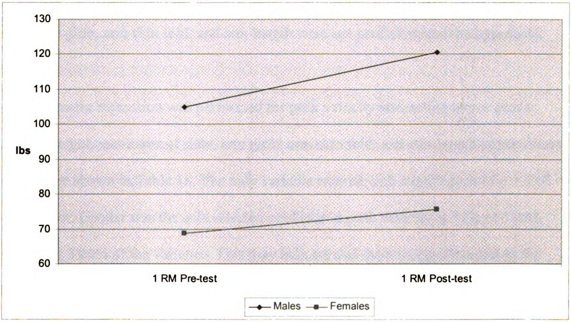


Figure 8. Plot of Means by Gender and Time on 1 RM

3. The variables of gender, weight, height, maturational state, arm girth, arm skin fold, and arm length will not be predictors of the dependent variables (1 RM, maximum velocity, and time to maximum velocity when lifting 35% of 1 RM).

A stepwise regression was performed for each of these dependent variables using the independent variables of gender, weight, height, maturational state, arm girth, arm skin fold, and arm length as predictors.

A stepwise regression was performed for time to maximum velocity at 35% of 1 RM attempting to use gender, weight, height, maturational state, arm girth, arm skin fold, and arm length as predictors. No variables entered with significance of $p > 0.05$. This is not surprising as none of the variables used correlated highly with time to maximum velocity at 35% of 1 RM. The same stepwise regression was performed for each gender separately and again no variables entered with significance of $p > 0.05$. Therefore, for time to maximum velocity at 35% of 1 RM the variables of gender, weight, height, maturational state, arm girth, arm skin fold, and arm length were not predictors and the hypothesis held.

A stepwise regression was performed for peak velocity attempting to use gender, weight, height, maturational state, arm girth, arm skin fold, and arm length as predictors. Results are shown in Table 18. The only variable entered with significance of $p > 0.05$ was gender. Gender was the sole selected predictor in peak velocity at 35% of 1 RM, predicting 33.6% of the variance. This may indicate that the training done during this study was not the major predictor in peak velocity and that genetics may play a role in maximum velocity.

Table 18: Regression Values for Peak Velocity

Variable	R	R^2	Change in R^2
Gender	.580	.336	.336

The same stepwise regression was performed for each gender separately. For females, no variables entered with significance of $p > 0.05$. Males had different results with arm skin fold entered with a significance of $p > 0.05$, $R = .661$, and $R^2 = .437$. The correlation for peak velocity and arm skin fold was $r = -.661$ meaning, the smaller the skin fold the higher the peak velocity. Peak velocity also had a high correlation with height ($r = -.608$) meaning, that the shorter the participant the higher the peak velocity. This is further confused by the fact that peak velocity also had a high correlations with arm length ($r = .418$) meaning, that the longer the participants arms the higher the peak velocity. It would be expected that participants with long arms would be taller. This may explain why, despite these high correlations for males in the study, arm length and height are not predictors of high velocity. For maximum velocity, the variable of gender was a predictor and the hypothesis did not hold. It should be noted that, because males and females had different results, when the regressions were performed separately, there would be separate models for predicting peak velocity.

A stepwise regression was performed for 1 RM attempting to use gender, weight, height, maturational state, arm girth, arm skin fold, and arm length as predictors ($p > 0.05$). The one variable that entered with significance of $p > 0.05$ was gender. As shown in Table 19, gender was the only predictor of 1 RM, accounting for 60.5% of the variance despite high correlations ($r > .300$) with several variables. This is due to the high correlation of gender to 1 RM ($r = .778$).

Table 19: Regression Values for 1 RM

Variable	R	R^2	Change in R^2
Gender	.778	.605	.605

When a regression was run without gender, males had no variable entered with significance of $p > 0.05$. For females body weight became the only predictor with $r = .604$. The correlation for 1 RM and body weight was $r = -.604$, meaning, the lighter the participant the higher the 1 RM. Arm length also had a high correlation with 1 RM ($r = -.593$), meaning, that the shorter the participants' arms, the higher the 1 RM. This is not necessarily contradictory, as participants with shorter arms could be lighter. This appears to be the case as arm length and weight correlate highly for females ($r = -.777$). For 1 RM the variable of gender was a predictor and the hypothesis did not hold. Due to the fact that males and females have different results, when the regressions were performed separately, there would be a separate model for predicting 1 RM.

Appendix H has a list of the correlation values for the variables used in the regression with both genders combined. Appendix H also lists males and females separately. Lastly, for more detail, Appendix H has a list of variables collected and their correlated values. The post-test values for height, weight, arm length, arm skin fold, and arm girth were used. Little to no change in height and weight occurred with the correlation of $r > 0.98$. This indicates little change occurred from pre-test to post-test. Weight training is not expected to affect height or arm length and should have a minimal impact on weight. Arm girth and arm skin fold are expected to change minimally, as is shown with correlations of $r = 0.73$ and 0.68, respectively. The mean change for arm girth was 0.6 cm and the mean change for arm skin fold was 6.3 mm.

CHAPTER 5

DISCUSSION, CONCLUSIONS, AND SUMMARY

Discussion

Discussion Based on Group Comparisons

When looking at the first hypothesis that no difference would be found between the high velocity and high force groups from pre-test to post-test in the change of 1 RM, change in maximum velocity when lifting 35% of 1 RM., or change in time to maximum velocity when lifting 35% of 1 RM. The hypothesis held for change in 1RM. This has significant implications for all people who weight train because it shows that a lighter load (35% of 1 RM) lifted at a high velocity will result in similar changes in 1 RM as lifting a heavier load (80% of 1 RM). The results of this study suggest that the force level required to lift a lighter weight at a faster rate may compensate for the lifting of a heavier weight at a slower frequency, if the goal is to increase 1 RM. Future studies are warranted to determine if simply weight training with any weight will increase 1 RM or if a high force level is required. It should be noted that when analyzing the force data of the ten selected participants, the average force (mass x acceleration) of the high force group was 49% more than the high velocity group, but the average of the peak forces for the high force group was only about 16% higher than the average peak force for the high velocity group.

The first hypothesis also held for peak velocity. This has significant implications for all people who weight train because it shows that a lighter load (35% of 1 RM) lifted at a high velocity will result in similar gains in peak velocity at 35% of 1 RM than lifting a heavier load (80% of 1 RM). Percent of 1 RM used for training may be a factor in determining the peak velocity at which to train; further testing should be done to determine if there is a different change in peak velocity if participants trained with the same weight, but at a different frequency.

The first hypothesis did not hold for time to peak velocity. What this implies for people who weight train is that to decrease time to peak velocity, training may not need to occur at peak velocity for a given load. A review of this data produces no obvious explanation for why this phenomenon occurred. All participants were tested at the same time and the equipment passed all calibration tests. It should be noted that the standard deviation was reduced to about half of the original values from pre-test to post-test, which indicates that some training did occur and the participants became more similar in their results for time to peak velocity. Why time to peak velocity was affected in this manner is not clear. This might be related to the fact that group also affected peak velocity, but it did not effect time to peak velocity in the same manner. One possible explanation is that participants in the high force group had to apply more force throughout the whole movement, while participants in the high velocity group had to apply a greater impulse at the beginning of each concentric contraction.

Discussion Based on Gender Comparisons

When looking at the second hypothesis that no differences between genders would be found from pre-test to post-test in 1 RM, maximum velocity when lifting 35% of 1 RM, or time to maximum velocity when lifting 35% of 1 RM. This hypothesis held for time to peak velocity, but did not hold for 1 RM and peak velocity. Therefore gender affects changed from pre-test to post-test in 1 RM and peak velocity, but not in time to peak velocity.

While both genders increased their 1 RM and peak velocity from pre-test to post-test, on average, males increased their time to peak velocity while females decreased their time. The difference in results for time to peak velocity was not found to be statistically significant, yet one possible explanation is that more time was needed to reach peak velocity due to the higher peak velocities that the males achieved. It should also be noted that only for time to peak velocity did the standard deviation become reduced to about half of the original values, which indicates that some training occurred and that the participants became similar in their results for peak velocity.

At first glace, it is surprising that, gender had such a big effect on change in 1 RM from pre-test to post-test. The mean Tanner stage was 4.55 with a standard deviation of 0.57. All males in the study were either at stage four or five, and only one female participant (stage three) fell below stage four. This was unexpected since one of the reasons that this age group was chosen was to ensure a wider range of Tanner stages. Anecdotally, when speaking to some of the students who chose not to participate in the study, it was found that potential participants with lower Tanner stages were reluctant to participate in the study because they may have been self-conscious of their maturity even though they were informed that the results were to be kept confidential. It is suspected that a wider range of Tanner stages would have altered the results of the study so that gender may not have had an effect on 1 RM.

Due to the advanced Tanner stage of the participants engaged in this study, it is not surprising that gender had an effect on 1 RM. A review of the literature substantiates that males have a greater hormonal response to weight training after they achieve maturation in comparison to equally mature females. Future research should be done to investigate why 1 RM was effected while time to peak velocity was not.

Discussion of the Regression Results

The third and final hypothesis was that the variables of gender, weight, height, maturational state, arm girth, arm skin fold, and arm length would not be predictors of the dependent variables (1 RM, maximum velocity, and time to maximum velocity at 35% 1 RM). This hypothesis held for time to peak velocity, but not for 1RM and peak velocity, both which had gender as a predictor. The fact that two parts of hypothesis three did not hold does not come as a surprise since the second hypothesis found that gender had a significant effect on peak velocity and 1 RM, the areas where hypothesis three also failed to hold.

Conclusions

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

1. If participants train at a high velocity using lighter weight (35% of 1 RM), can they increase the amount of force (1 RM) generated as much as if they train at a high force (80% of 1 RM)?

The answer to this question was clearly yes. Hypothesis one in chapter four showed that group had no effect on change in 1 RM and both groups had a significant increase from pre-test to post-test, but between the two different training groups the difference was not significant. This has significant implications for all people who weight train because it shows that a lighter load (35% of 1 RM) lifted at a high velocity will result in similar changes in 1 RM as lifting a heavier load (80% of 1 RM). The results of this study suggest that the force level required to lift a lighter weight at a faster rate may compensate for the lifting of a heavier weight at a slower frequency, if the goal is to increase 1 RM.

2. If participants trained two times per week over a 15 week period at a high force (i.e., 80% of 1 RM at a self-selected frequency of repetition), can they increase the peak velocity generated when lifting lighter weights (i.e., 35% of 1 RM) and the time to peak velocity as much as if they had trained at a lighter weight (i.e., 35% of 1 RM at a high frequency of repetition)?

The answer to the first part of question was clearly yes, as hypothesis one in chapter four showed that participants from both groups had a significant increase in peak velocity from pre-test to post-test, but between the two different training groups the difference was not significant. This has significant implications for all people who weight train because it shows that a lighter load (35% of 1 RM) lifted at a high velocity will result in similar changes in peak velocity at 35% of 1 RM than lifting a heavier load (80% of 1 RM). The answer to the second part of the question was no, as hypothesis one in chapter four showed that participants from both groups had a significant increase in time to peak velocity from pre-test to post-test, but between the two different training groups the difference was significant.

Because both groups were able to increase both their 1 RMs and their peak velocity, it appears that the location training occurs on the force curve does not affect the ability to increase force over the whole curve. In other words, force will be increased over the whole curve regardless of where on the curve training occurs.

3. If high school male and female participants trained two times per week over a 15 week period with the same protocol, does gender affect their ability to increase

the amount of maximum force (1 RM), peak velocity generated when lifting lighter weights (i.e., 35% of 1 RM), and the time to peak velocity?

Again the answer to this question was yes. Gender did have an effect, especially on change in 1 RM, which is what was used as a measure of force. The average change for females was 7 lbs, while the average change in 1 RM for males was 16 lbs. This was more than double the amount for females. Gender also had an effect on change in peak velocity, which is what was used as a measure of velocity. The average change for females was 8 cm/s, while the average change for males was 15 cm/s, almost double the females' change.

4. How do two different weight training programs (i.e., high frequency at 35% of 1 RM and high force associated with 80% of 1 RM at a self-selected frequency of repetition) affect biomechanical parameters (i.e., complete velocity pattern of the weight for all repetitions of weight taken every 10 milliseconds) over 15 weeks?

The shape of the velocity patterns did not change significantly, but they did change in amplitude. The minimum and maximum values of the velocity curves increased. This supports the contention that training occurred for both groups.

Recommendations for Future Studies

This study produced some clear results and some not so clear results. Gender is definitely a factor in 1 RM and peak velocity when comparing sexually mature males and females. No difference in change in 1 RM or peak velocity was seen whether participants trained with high force or high velocity. When training with either method, participants had a significant increase in their 1 RM and a significant increase in their peak velocity. Time to peak velocity is more confusing. The standard deviation for time to peak velocity decreased greatly, which suggests that the participants became more similar in time to peak velocity due to training. Yet, gender had a significant effect as the males increased their time to peak velocity and the high velocity group increased their time to peak velocity. No variable predicted time to peak velocity.

Since the inception of this study, other research has been published which ties in with the results of the current study. Liow and Hopkins (2003), using slow training and explosive training with a control group, found that all groups improved strength and sprint performance, but they concluded that slow weight training was more effective than explosive training for improving acceleration when force is high throughout the movement. This could help to explain why the high velocity group had an increase in time to peak velocity. This does not agree with earlier studies such as Morrissey, Harman, Frykman, and Han (1998) who found that their fast group improved strength most at the faster velocities, while the slow group's strength changes were consistent across the velocities tested. Liow and Hopkins also agree with the findings of Stone et al. (2003) that to improve jumping power, one should shift from lighter to heavier loads.

The result for time to peak velocity does not make obvious sense on the surface and more research will have to be done to determine why males and the high velocity group increased their time to peak velocity. Newton et al. (1996) suggested that fast movements with light loads do not approximate movements in sports such as a throw because the resistance is not accelerated throughout the movement. This agrees with the findings of Cronin, McNair, and Marshall (2003) who examined force and velocity with loads of 30, 40, 50, 60, 70, and 80% of 1 RM and found the expected result that force increases and velocities decreases as weight is increased. They concluded that the advantage of the slower, heavier weight is that it removes the elastic energy from the movement. The advantage of lighter weights is that the acceleration/deceleration profile is similar to that encountered in an athletic environment.

Practical Implications for Coaches

What are the implications for the practitioner from this study? The most relevant result is no difference in change in 1 RM or peak velocity occurs if a person trains with high force or high velocity and there will likely be a significant change no matter which training method is used. This finding is similar to Hoffman et al. (2004) who found that Olympic and traditional powerlifting produced statistically identical results for six different field measures related to football. Since training with one method provides no benefit over the other, this author suggests that people weight train using both methods. This would be equivalent to doing contrast training which was supported by several studies in the review of literature. This has the added benefit of increased variety when using other methods of resistance training. Baker (2003) found an increase in power output by alternating heavy and light resistances. These are two very good reasons to use both high velocity and high force alternately when doing resistance training.

APPENDICES

Appendix A

Appendix A

INFORMED WRITTEN CONSENT FORM

COMPARISON OF SELECTED KINETIC VALUES OF TWO DIFFERENT WEIGHT TRAINING METHODS

For the participants/parents (of subject under 18 years of age) in the study of different modalities of weight training

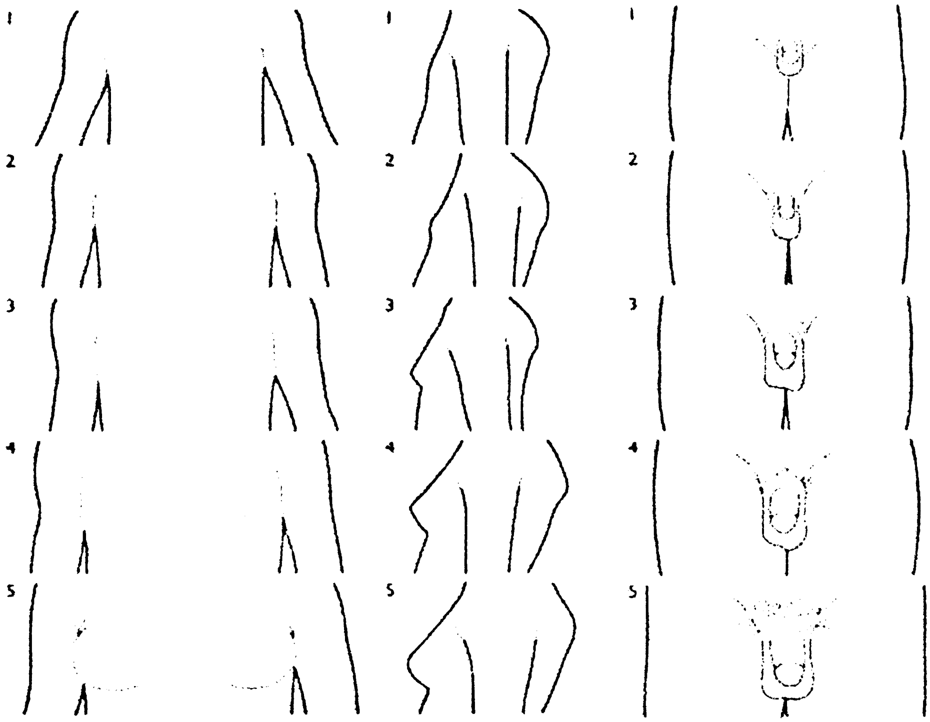
The purpose of this study is to examine the relationship between various biomechanical measures (e.g. weight lifted, peak velocity, time to peak velocity) and how these measures change in relation to the method of weight training. This study will take 13 weeks to complete.

Each participant will be randomly assigned to one of two treatment groups and train two times a week for eight weeks. One treatment group will do one set of 10 repetitions of the seated shoulder press using 35% of their one repetition maximum (1 RM) with their maximum repetition frequency and the other treatment group will do one set using 80% of their 1 RM for the seated shoulder press attempting to complete up to 10 repetitions with their normal repetition frequency. Each training session will take approximately one minute to complete.

Items of Consent:

1. You have read the purpose of the study.
2. The names of the participants will not be associated with any publication and/or presentation of the data collected in this study.
3. Videotapes will be taken of your (child's) performances and that these tapes may be used for demonstrations, instruction, and study.
4. Participation in this study does not guarantee any beneficial results.
5. If you (your child and/or yourself) would like additional information and have questions about this study, you may contact the investigators at 623-6001 for further explanations and answers to your questions.
6. You (your child and/or yourself) may receive a copy of your child's personal assessment data after the study has been completed.
7. You (your child) will not receive any extra credit for participating in this study.
8. You (your child has) have no history of prior injuries that could be aggravated by participation in this study.
9. There is always a slight risk of injury when people are involved with weight training. If you are injured as a result of your participation in this research project, Michigan State University will assist you in obtaining medical care if necessary for your research related injuries. If you have insurance for this medical care, your insurance carrier may be billed in the ordinary manner. You will be reimbursed by (MSU or another payee) for non-covered research related medical expenses, including deductibles. This does not mean you are giving up any legal rights you may have. You may contact Dr. Eugene W. Brown (517) 353-6491 with any questions.

10. You (your child) will be asked to do a self-assessment of his or her Tanner stag using the drawings below. This is important to the study because maturity will impact the hormonal effect of resistance training. Participants will only see the drawing of their own gender.



11. The participants are free to discontinue involvement in this study at any time without penalty.
12. Your privacy will be protected to the maximum extent allowable by law.
13. If you have any questions about this study, please contact Jerome Learman by phone (517) 623-6001, by email (learmanj@msu.edu) or by regular mail PO Box 162, Dansville, MI 48819 or Dr. Eugene W. Brown by phone (517) 353-6491, by email (ewbrown@msu.edu) or by regular mail 204 IM Sports Circle, East Lansing, MI 48824. If you have questions or concerns regarding your rights as a study participant, or are dissatisfied at any time with any aspect of this study, you may contact – anonymously, if you wish – Ashir Kumar, M.D., Chair of the University Committee on Research Involving Human Subjects (UCRIHS) by phone: (517) 355-2180, fax: (517) 432-4503, e-mail: ucrihs@msu.edu, or regular mail: 202 Olds Hall, East Lansing, MI 48824.
14. You freely consent to (allow your child to) take part in this scientific study being conducted by Jerome M. Learman and Dr. Eugene W. Brown of Michigan State University.

______________________	______________	______________________
Signature of participant	Date	Phone number of participant
______________________	______________	______________________
Signature of parent (guardian)	Date	Phone number of parent/guardian

INFORMED WRITTEN ASSENT FORM

COMPARISON OF SELECTED KINETIC VALUES OF TWO DIFFERENT WEIGHT TRAINING METHODS

For the participants (under 18 years of age) in the study of different modalities of weight training

The purpose of this study is to examine the relationship between various biomechanical measures (e.g. weight lifted, peak velocity, time to peak velocity) and how these measures change in relation to the method of weight training. This study will take 13 weeks to complete.

Each participant will be randomly assigned to one of two treatment groups and train two times a week for eight weeks. One treatment group will do one set of 10 repetitions of the seated shoulder press using 35% of their one repetition maximum (1 RM) with their maximum repetition frequency and the other treatment group will do one set using 80% of their 1 RM for the seated shoulder press attempting to complete up to 10 repetitions with their normal repetition frequency. Each training session will take approximately one minute to complete.

Items of Consent:

1. You have read the purpose of the study.
2. The names of the participants will not be associated with any publication and/or presentation of the data collected in this study.
3. Videotapes will be taken of your performances and that these tapes may be used for demonstrations, instruction, and study.
4. Participation in this study does not guarantee any beneficial results.
5. If you would like additional information and have questions about this study, you may contact the investigators at 623-6001 for further explanations and answers to your questions.
6. You may receive a copy of your personal assessment data after the study has been completed.
7. You will not receive any extra credit for participating in this study.
8. You (your child has) have no history of prior injuries that could be aggravated by participation in this study.
9. There is always a slight risk of injury when people are involved with weight training. If you are injured as a result of your participation in this research project, Michigan State University will assist you in obtaining medical care if necessary for your research related injuries. If you have insurance for this medical care, your insurance carrier may be billed in the ordinary manner. You will be reimbursed by (MSU or another payee) for non-covered research related medical expenses, including deductibles. This does not mean you are giving up any legal rights you may have. You may contact Dr. Eugene W. Brown (517) 353-6491 with any questions.

10. You asked to do a self-assessment of your Tanner stage. This is important to the study because maturity will impact the hormonal effect of resistance training.
11. The participants are free to discontinue involvement in this study at any time without penalty.
12. Your privacy will be protected to the maximum extent allowable by law.
13. If you have any questions about this study, please contact Jerome Learman by phone (517) 623-6001, by email (learmanj@msu.edu) or by regular mail PO Box 162, Dansville, MI 48819 or Dr. Eugene W. Brown by phone (517) 353-6491, by email (ewbrown@msu.edu) or by regular mail 204 IM Sports Circle, East Lansing, MI 48824. If you have questions or concerns regarding your rights as a study participant, or are dissatisfied at any time with any aspect of this study, you may contact – anonymously, if you wish – Ashir Kumar, M.D., Chair of the University Committee on Research Involving Human Subjects (UCRIHS) by phone: (517) 355-2180, fax: (517) 432-4503, e-mail: ucrihs@msu.edu, or regular mail: 202 Olds Hall, East Lansing, MI 48824.
14. You freely consent to take part in this scientific study being conducted by Jerome M. Learman and Dr. Eugene W. Brown of Michigan State University.

____________________ ______________ ________________________

Signature of participant   Date   Phone number of participant

Appendix B

Appendix B

FITRO DYNE PC

Adopted from the WEBA Sports web site: http://www.weba-sport.com/fitro_dyne.html, July 2004).

PRINCIPLE

Fitro dyne is a system working on the simple principle of mechanics saying that actual force is a product of acceleration and mass. (Since the velocity and acceleration change during the lifting exercise, so does the actual force and also the other variables, e.g. power. Therefore, lifting the same weight in a more dynamic way with pronounced acceleration produces a higher peak force than a slowly performed lift. Also counter movement exercise produces much higher peaks than lift from rest position. Differences in parameters like force and power (which may be well quantified by this system) due to different physiological mechanisms involved in control of muscle contraction. One may, therefore, expect also different adaptation patterns.)

Acceleration of vertical movements (above or below g) is being obtained by derivation of vertical velocity, measured by highly precise analogue device mechanically coupled with a barbell or weights of an exercise machine (also complex lifting movement like clean and jerk or snatch can be monitored). In addition, power is being calculated as a product of force and velocity, the actual position by integration of velocity.

However, to be able to carry out these calculations, you have to enter mass of barbell or weights on the exercise machine first.

CONSTRUCTION

Technically the system consists of 2 functional components, a sensor and an electronic unit, stored in a small box of about 28x13x7, 5 cm.

The sensor unit contains a precise analog velocity sensor and an infrared impulse sensor with resolution of 3 mm. Both are mechanically coupled with the reel. While pulling the tether out of the reel, this rotates and velocity is being measured. Back movement of the reel is guaranteed by string producing force of about 2 N. The tether can be pulled out to the distance of about 2.5 meter.

The other end of the tether is to be connected by means of a small hook either to the barbell axis or to the weights of the weight exercise machine. The attachment is easy and does not take more than several seconds.

The electronic box contains the signal modification part, a 12 bit AD converter and an acoustic device for differential signalization of reaching preset lower and upper positions during exercise (range of motion) as well as decrease of power under preset level. Use of signalization is optional, you can switch it on or off in a software setup.

The electronic box communicates with the computer by means of COM1. You can use any IBM-compatible computer (even 286); clock speed does not play any role. The only requirement is a VGA card and a VGA monitor (color or monochrome).

SOFTWARE

Comprehensive software allows you to collect, calculate and on-line display the basic biomechanical parameters involved with the weight exercise. Of course you can store the data for further analyses of single repetitions or the whole set.

During the diagnostic measurement a movement of symbolic barbell axis and graph of any of derived parameter, i.e. velocity, force, power or acceleration. After each repetition you receive a summary of mean and peak data in digital form, separately for eccentric and concentric phase.

The calibration of the system is software driven and basically very simple. This is due to simultaneous registration of velocity and distance. According to instructions on the screen you only have to pull the tether the defined distance between 50 and 100 cm (system calibrates the distance) and then to pull at least 50 cm with medium velocity (system calibrates the velocity). The calibration is in fact stable, a recalibration is necessary only if you use an exercise machine, in which - due to other than 1:1 levering - the weights are moved with different velocity than axis at which force is being applied. In this case you move the axis while performing calibration.

Producer:
FiTRONiC

Appendix C

Appendix C

SAMPLE OF DATA COLLECTED FROM A PARTICIPANT PERFORMING THE SEATED SHOULD PRESS

A graph of this information is at the end of the data set

- Name = Hour - participant number – week - day of the week
- Therefore this is:
  - 3rd hour
  - participant 3
  - the 5th week of the study,
  - the 2nd day of training that week
- Inclination: 0 grades: The weight moved vertically up and down, not at an angle.
- Weight is the weight lifted in kilograms. This participant is lifting 11kg.

Bold text is concentric movement and normal text is eccentric movement. Therefore, the data represent the first of ten complete repetitions beginning with concentric contraction and ending with eccentric contraction.

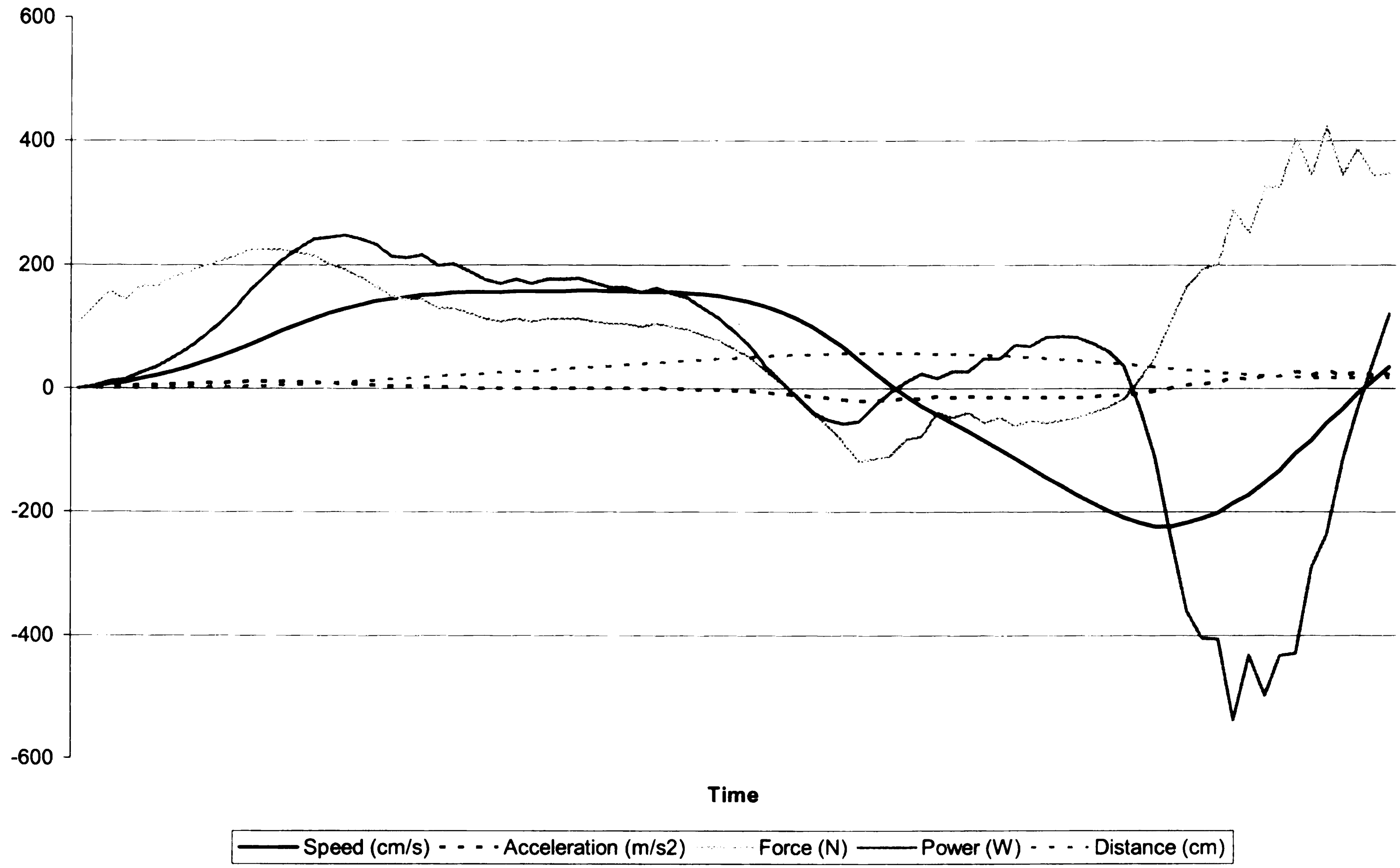
Name: 3-3-5-2
Inclination: 0 grades
Date: 23.10.2003
Time: 12:15:42
Weight: 11

Time (ms)	Speed (cm/s)	Acceleration (m/s2)	Force (N)	Power (W)	Distance (cm)
10	**0**	**0**	**107.9**	**0**	**0**
20	**2.4**	**2.4**	**134.6**	**3.3**	**0**
30	**6.9**	**4.4**	**156.8**	**10.8**	**0**
40	**10.1**	**3.2**	**143.5**	**14.5**	**0**
50	**15.4**	**5.3**	**165.7**	**25.5**	**0**
60	**20.6**	**5.3**	**165.7**	**34.2**	**0.5**
70	**27.1**	**6.5**	**179.1**	**48.5**	**0.5**
80	**34.4**	**7.3**	**188**	**64.6**	**1**
90	**42.5**	**8.1**	**196.9**	**83.6**	**1.5**
100	**51.3**	**8.9**	**205.8**	**105.7**	**2.1**
110	**61.1**	**9.7**	**214.7**	**131**	**2.6**
120	**71.6**	**10.5**	**223.5**	**160**	**3.1**
130	**82.1**	**10.5**	**223.5**	**183.5**	**4.1**
140	**92.6**	**10.5**	**223.5**	**207**	**5.1**
150	**102.7**	**10.1**	**219.1**	**225**	**6.2**
160	**112.4**	**9.7**	**214.7**	**241.3**	**7.2**
170	**120.9**	**8.5**	**201.3**	**243.4**	**8.7**
180	**128.6**	**7.7**	**192.4**	**247.4**	**10.3**
190	**135**	**6.5**	**179.1**	**241.8**	**11.3**
200	**140.3**	**5.3**	**165.7**	**232.5**	**12.8**
210	**143.9**	**3.6**	**147.9**	**212.9**	**14.4**
220	**147.2**	**3.2**	**143.5**	**211.2**	**15.9**

230	150.4	3.2	143.5	215.8	17.5
240	152.4	2	130.1	198.4	19
250	154.5	2	130.1	201	20.5
260	155.7	1.2	121.3	188.7	22.1
270	156.1	0.4	112.4	175.4	23.6
280	156.1	0	107.9	168.4	25.2
290	156.5	0.4	112.4	175.8	26.7
300	156.5	0	107.9	168.8	28.2
310	156.9	0.4	112.4	176.3	29.8
320	157.3	0.4	112.4	176.7	31.3
330	157.7	0.4	112.4	177.2	32.9
340	157.7	0	107.9	170.2	34.4
350	157.3	-0.4	103.5	162.7	35.9
360	156.9	-0.4	103.5	162.3	38
370	156.1	-0.8	99	154.5	39
380	155.7	-0.4	103.5	161.1	41.1
390	154.9	-0.8	99	153.3	42.1
400	153.6	-1.2	94.6	145.3	44.2
410	151.6	-2	85.7	129.9	45.2
420	148.8	-2.8	76.8	114.2	47.2
430	144.7	-4	63.4	91.8	48.3
440	139.5	-5.3	50.1	69.9	49.8
450	132.2	-7.3	27.9	36.8	51.4
460	123.3	-8.9	10.1	12.4	52.4
470	112.4	-10.9	-12.2	-13.7	53.4
480	99.1	-13.3	-38.9	-38.5	54.4
490	83.7	-15.4	-61.1	-51.1	55.5
500	65.9	-17.8	-87.8	-57.9	56
510	45.3	-20.6	-118.9	-53.8	56.5
520	25.1	-20.2	-114.5	-28.7	56.5
530	5.3	-19.8	-110	-5.8	56.5
540	-12.1	-17.4	-83.3	10.1	56.5
550	-29.1	-17	-78.9	23	56
560	-42.5	-13.3	-38.9	16.5	55.5
570	-56.6	-14.2	-47.8	27	54.9
580	-69.9	-13.3	-38.9	27.2	54.4
590	-84.9	-15	-56.6	48.1	53.4
600	-99.1	-14.2	-47.8	47.3	52.4
610	-114.4	-15.4	-61.1	69.9	51.4
620	-129	-14.6	-52.2	67.3	49.8
630	-143.9	-15	-56.6	81.5	48.3
640	-158.5	-14.6	-52.2	82.7	46.7
650	-172.6	-14.2	-47.8	82.4	45.2
660	-186	-13.3	-38.9	72.3	43.1
670	-198.5	-12.5	-30	59.5	41.1
680	-209.8	-11.3	-16.6	34.9	39
690	-218.3	-8.5	14.5	-31.7	36.5
700	-223.6	-5.3	50.1	-112	34.4
710	-223.6	0	107.9	-241.3	31.8
720	-218.3	5.3	165.7	-361.8	29.8

730	-210.7	7.7	192.4	-405.3	27.7
740	-202.2	8.5	201.3	-407	25.7
750	-185.6	16.6	290.3	-538.7	23.6
760	-172.6	12.9	250.2	-432	22.1
770	-152.8	19.8	325.8	-498	20.5
780	-133	19.8	325.8	-433.4	19
790	-105.9	27.1	405.9	-430	18.5
800	-84.5	21.4	343.6	-290.4	17.5
810	-55.8	28.7	423.7	-236.4	16.9
820	-34.4	21.4	343.6	-118.1	16.9
830	-8.9	25.5	388.1	-34.5	16.9
840	12.5	21.4	343.6	43.1	16.9

Graph of Data



Appendix D

Appendix D

GUIDELINES FOR THE SHOULDER PRESS

Adopted from the Essentials of Strength Training and Conditioning (Baechle, 1994).

Beginning Position
- Grasp Handles with a closer pronated grip.
- Sit or stand and assume a flat back position.
- Position feet on the floor or on the rungs of the seat.
- Focus eyes straight ahead.

Upward Movement Phase
- Push handles up.
- Keep elbows pointed out to sides until arms are fully extended.
- Maintain body position.
- Do not forcefully lock out elbows.

Downward Movement Phase
- Lower handles slowly and under control to shoulder level.
- Do not jerk or bounce at bottom of movement.

Breathing
- Exhale through the sticking point of the upward movement phase.
- Inhale on the downward movement phase.

Appendix E

Appendix E

PERSONAL DATA SHEET

Name ________________________

Date of Birth __/__/___

Athletic Playing Experience (please list every sport played in school or out of school by year, starting with kindergarten)

Sport Played	Year (in school)

INFORMATION BELOW IS TO BE FILLED OUT BY THE RESEARCHERS

Anthropometric Data

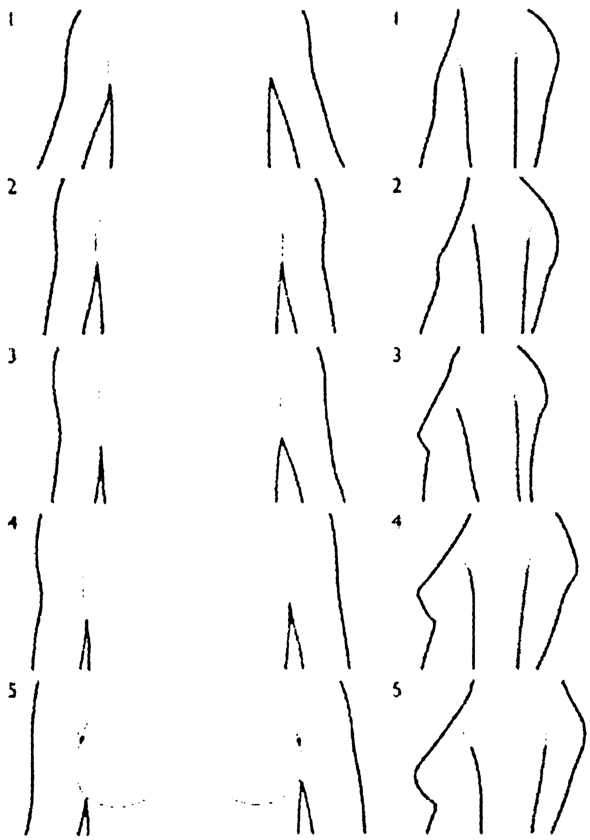
Standing height (mm) _____ Sitting height (mm) _____

Arm length (mm) _____ Weight (kg) ______

Weight used for 1 RM shoulder press (lbs) ______in (kg) _______

Name of computer file(s) with velocity data: ___________________________________

- You are being asked to self assess your sexual maturity.
- You can use the pictures below and the descriptions.
- Try to pick the picture that looks the most like you.



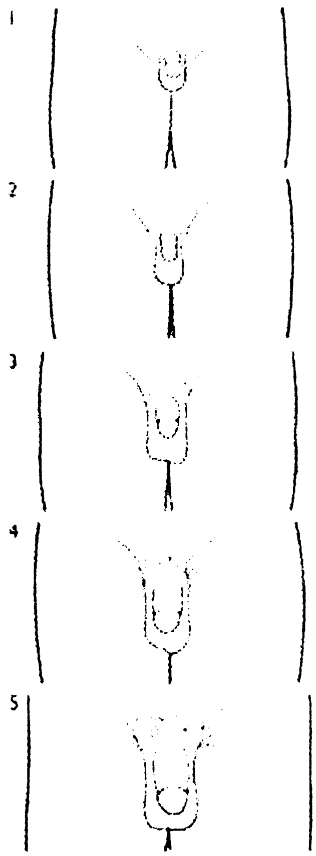
Female scoring

1. Same as in childhood.
2. Breast buds visible.
3. Enlargement of breast, areola.
4. Areola rises above rest of breast.
5. Areola no longer projects from breast.

Circle The Tanner Stage 1-5 that most resembles yourself:

1 2 3 4 5

- You are being asked to self assess your sexual maturity.
- You can use the pictures below and the descriptions.
- Try to pick the picture that looks the most like you.



Male scoring

1. Same as in childhood.
2. Enlargement of-testes, scrotum.
3. Penis lengthened.
4. Scrotum darkened, penis width increases, glands develop.
5. Pubic hair spreads to medial aspect of thighs.

Circle The Tanner Stage 1-5 that most resembles yourself:

1 2 3 4 5

Appendix F

Appendix F

MEASUREMENT GUIDELINES

Adopted from the Anthropometric Standardization Reference Manual (Lohman, Roche, and Martorell, 1988).

Weight: An electronic scale will be used. The participant stands on the center of the scale's platform with body weight evenly distributed over both feet. The participant will wear gym shorts, appropriate undergarments, a t-shirt and socks, but no shoes. The scale being used is calibrated annually and is accurate to the nearest tenth of a pound or kilogram.

Standing Height: A standing anthropometer will be used. The participant will stand with body weight evenly distributed over both feet and the head will be position horizontally. The arms will hang freely by the sides of the trunk, with the palms facing the thighs. The heels are placed together and the medial boarders of the feet are at about a 60-degree angle. The participant is asked to inhale deeply and maintain posture. Height will be measured from the highest point on the head with sufficient pressure to compress the hair. The participant will wear socks, but no shoes.

Arm Girth: A steel tape will be used. The participant stands with the right arm abducted, elbow flexed, and the forearm supinated. The tape is positioned around the arm. The participant is them requested to clench the fist, fully flex the elbow and contract the biceps as strongly as possible. The tapes is then positioned so that it is perpendicular to the long axis of the arm and located at the place of maximum circumference.

Arm length: An anthropometer will be used. The participant will stand with body weight evenly distributed over both feet and the head will be positioned horizontally. The right arm will be measured at about a 70-degree angle to the ground. The left arm will hang freely by the side of the trunk. Both palms will be facing the thighs. The heels are placed together and the medial boarders of the feet are about at a 60-degree angle. The participant is asked to maintain posture. Length will be measured from the acrommial process to the end of the third digit.

Appendix G

Appendix G

BI-WEEKLY PHYSICAL ACTIVITY LOG

Bi-Weekly Physical Activity Log for: ____________________ Date: ________

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Activities: 1: 2. Intensity: 1. 2. Minutes: 1. 2.	Activities: 1: 2. Intensity: 1. 2. Minutes: 1. 2.	Activities: 1: 2. Intensity: 1. 2. Minutes: 1. 2.	Activities: 1: 2. Intensity: 1. 2. Minutes: 1. 2.	Activities: 1: 2. Intensity: 1. 2. Minutes: 1. 2.	Activities: 1: 2. Intensity: 1. 2. Minutes: 1. 2.	Activities: 1: 2. Intensity: 1. 2. Minutes: 1. 2.
Activities: 1: 2. Intensity: 1. 2. Minutes: 1. 2.	Activities: 1: 2. Intensity: 1. 2. Minutes: 1. 2.	Activities: 1: 2. Intensity: 1. 2. Minutes: 1. 2.	Activities: 1: 2. Intensity: 1. 2. Minutes: 1. 2.	Activities: 1: 2. Intensity: 1. 2. Minutes: 1. 2.	Activities: 1: 2. Intensity: 1. 2. Minutes: 1. 2.	Activities: 1: 2. Intensity: 1. 2. Minutes: 1. 2.

1. List your daily activities. If you need to, use more than one sheet per day and staple them together.
2. Assign each an intensity level - (low, med, high).
3. Indicate how many minutes each activity lasted.

Low intensity exercises include easy walking, household chores, light gardening, etc. Moderate intensity exercises include brisk walking or easy jogging, moderately paced bicycling, etc., and high intensity exercises include fast running, lap swimming, jumping rope, heavy lifting, etc.
Adopted from the Let's Get Moving web site:
http://commtechlab.msu.edu/sites/letsnet/Frames/Subjects/health/b8u411.html

Appendix H

Appendix H — CORRELATIONS OF SELECTED VARIABLES

	Gen	RM1	Vel1	TV1	GP	RM2	Vel2	TV2	CRM	CPV	CTPV	HT	WT	TN	AG	AL	ASF
Gen	1.00	.722	.289	-.254	.033	.778	.580	.216	.651	.217	.397	.200	.493	.257	.365	.595	-.414
RM1	.722	1.00	.055	-.527	.033	.980	.712	.089	.478	.507	.520	.088	.232	.353	.403	.392	-.496
Vel1	.289	.055	1.00	-.292	.270	.047	.195	.250	-.003	-.651	.457	-.191	.276	.003	-.227	.178	-.383
TV1	-.254	-.527	-.292	1.00	-.145	-.503	-.562	.402	-.194	-.201	-.856	.233	-.182	-.281	.025	-.300	.498
GP	.033	.033	.270	-.145	1.00	.083	.342	.411	.080	.048	.389	-.099	.074	.089	-.297	.073	-.221
RM2	.778	.980	.047	-.503	.083	1.00	.692	.011	.645	.498	.551	.180	.252	.348	.485	.391	-.451
Vel2	.580	.712	.195	-.562	.342	.692	1.00	.237	.318	.617	.475	.045	.317	.406	.110	.522	-.487
TV2	.216	-.089	.250	.402	.411	.011	-.237	1.00	.388	.364	.129	.302	.085	-.023	.077	-.123	.052
CRM	.651	.478	-.003	-.194	.080	.645	.318	.388	1.00	.249	.429	.451	.220	.177	.584	.259	-.085
CPV	.217	.507	-.651	-.201	.048	.498	.617	-.364	.249	1.00	.001	.118	.025	.312	.267	.261	-.070
CTPV	.397	.520	.457	-.856	.389	.551	.475	.129	.429	.001	1.00	-.082	.245	.291	.070	.256	-.510
HT	.200	.088	-.191	.233	-.099	.180	-.045	.302	.451	.118	-.082	1.00	.285	.252	.830	.204	.686
WT	.493	.232	.276	-.182	.074	.252	.317	.085	.220	.025	.245	.285	1.00	.045	.220	.800	-.170
TN	.257	.353	.003	-.281	.089	.348	.406	-.023	.177	.312	.291	.252	.045	1.00	.387	.216	.055
AG	.365	.403	-.227	.025	-.297	.485	.110	.077	.584	.267	.070	.830	.220	.387	1.00	.274	.428
AL	.595	.392	.178	-.300	.073	.391	.522	-.123	.259	.261	.256	.204	.800	.216	.274	1.00	-.196
ASF	-.414	-.496	-.383	.498	-.221	-.451	-.487	.052	-.085	-.070	-.510	.686	-.170	.055	.428	-.196	1.00

Abbreviation	Variable	Mean	Standard Deviation	Units
Gen	Gender	.		
RM1	Pre-test of 1 RM	87.42	25.56	lbs
Vel1	Pre-test Peak velocity	163.65	16.94	cm/s
TV1	Pre-test Time to Peak velocity	365.48	136.48	ms
GP	Training group	.48	.51	
RM2	Post-test of 1 RM	98.87	29.37	lbs
Vel2	Post-test Peak velocity	174.30	16.35	cm/s
TV2	Post-test Time to Peak velocity	411.61	71.09	ms
CRM	Change in 1 RM from Pre to Post-test	11.45	6.73	lbs
CPV	Change in peak velocity from Pre to Post-test	10.64	21.11	cm/s
CTPV	Change in time to peak velocity from Pre to Post-test	46.13	126.03	ms
HT	Height	167.11	6.17	cm
WT	Weight	69.11	14.39	kg
TN	Tanner Stage	4.55	.57	
AG	Arm Girth	29.97	3.44	cm
AL	Arm Length	69.21	3.54	cm
ASF	Arm Skin fold	13.61	5.99	mm

Correlation Values of Variables Used in Regression

	1 RM	PV	Time to PV	Gender	Height	Weight	Tanner Stage	Arm Girth	Arm Length	Arm Skin fold
1 RM	1.000	.692	.011	.778	.180	.252	.348	.485	.391	-.451
PV*	.692	1.000	-.237	.580	-.045	.317	.406	.110	.552	-.487
Time to PV*	.011	-.237	1.000	.216	.302	.085	.023	.077	-.123	.052
Gender	.778	.580	.216	1.000	.200	.493	.257	.365	.595	-.414
Height	.180	-.045	.302	.200	1.000	.285	.252	.830	.204	.686
Weight	.252	.317	.085	.493	.285	1.000	.045	.220	.800	-.170
Tanner Stage	.348	.406	-.023	.257	.252	.045	1.000	.387	.216	.055
Arm Girth	.485	.110	.077	.365	.830	.220	.387	1.000	.274	.428
Arm Length	.391	.552	-.123	.595	.204	.800	.216	.274	1.000	-.196
Arm Skinfold	-.451	-.487	.052	-.414	.686	-.170	.055	.428	-.196	1.000

PV = Peak Velocity

Correlation Values for Males of Variables Used in Regression

	1 RM	PV	Time to PV	Height	Weight	Tanner Stage	Arm Girth	Arm Length	Arm Skinfold
1 RM	1.000	.621	-.508	-.020	-.057	.255	.413	.185	-.323
PV*	.621	1.000	-.759	-.608	-.125	.085	-.266	.418	-.661
Time to PV*	-.508	-.759	1.000	.363	.019	-.016	.049	-.487	.295
Height	-.020	-.608	.363	1.000	.134	-.137	.872	-.227	.864
Weight	-.057	-.125	.019	.134	1.000	-.544	.072	.621	-.135
Tanner Stage	.255	.085	-.016	-.137	-.554	1.000	.127	-.100	-.016
Arm Girth	.413	-.266	.049	.872	.072	.127	1.000	-.086	.667
Arm Length	.185	.418	-.487	-.227	.621	-.100	-.086	1.000	-.286
Arm Skinfold	-.323	-.661	.295	.864	-.135	-.016	.667	-.286	1.000

PV = Peak velocity.

Correlation Values for Females of Variables Used in Regression

	1 RM	PV	Time to PV	Height	Weight	Tanner Stage	Arm Girth	Arm Length	Arm Skinfold
1 RM	1.000	.281	.354	.204	-.604	.301	.254	-.593	.084
PV*	.281	1.000	-.120	.288	.164	.507	-.009	.205	.122
Time to PV*	.354	-.120	1.000	.126	-.067	-.150	-.065	-.249	-.095
Height	.204	.288	.126	1.000	.381	.581	.788	.366	.867
Weight	-.604	.164	-.067	.381	1.000	.164	.033	.777	.258
Tanner Stage	.301	.507	-.150	.581	.164	1.000	.033	.777	.258
Arm Girth	.254	-.009	-.065	.788	.033	.490	1.000	.173	.748
Arm Length	-.593	.205	-.249	.366	.777	.161	.173	1.000	.394
Arm Skinfold	.084	.122	-.095	.867	.258	.451	.748	.394	1.000

* PV = Peak velocity.

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BIBLIOGRAHPY

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