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Date

EFFECT OF EXPLOSIVE UPPER BODY EXERCISES ON BIOMECHANICAL PARAMETERS IN MALES 18-30 YEARS OF AGE

By

Kris William Kotrla

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ABSTRACT

EFFECT OF EXPLOSIVE UPPER BODY EXERCISES ON BIOMECHANICAL PARAMETERS IN MALES 18-30 YEARS OF AGE

By

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The purpose of this study was to examine the relationships that exist between selected upper body exercises (push-up and medicine ball throw) and biomechanical parameters (force, maximal rate of force development (MRFD), and average peak power output) in males who are currently resistance training. Relationships were expected to exist between biomechanical parameters in response to the demand of exercise methods (concentric only, countermovement, and plyometric) performed with a push-up and throwing a 3 kg medicine ball. The design was a cross sectional, descriptive study with repeated measures. In this study individuals were randomly assigned into one of two groups. The results of this study indicated that push-up exercises require a significantly higher peak force and MRFD to perform more explosively than 3 kg medicine ball throws. The average peak power output was greater for the 3 kg medicine ball throws for the countermovement and plyometric method, but no significant difference was found between the exercises. In addition, explosive upper body exercises that rely on the stretch shortening cycle (SSC) were shown to develop higher magnitudes of force in comparison to concentric only methods. The MRFD and average peak power output were significantly greater when the plyometric method was compared to the concentric only and countermovement method. This study and future studies of this type could help bridge the gap between exercise scientists and coaches in determining which exercises would be the most beneficial for athletes.

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CHAPTER 1
INTRODUCTION

Overview of Problem

This study was conducted to show selected relationships between biomechanical parameters and explosive upper body exercises. Exercise science professionals agree that analysis of performance parameters associated with upper body exercise is lacking (Davies & Matheson, 2001; Knudson, 2001). Unparalleled to the amount of research on exercise involving the lower body are relatively few studies conducted to investigate upper body movements and variables that are influenced by them (Bloomfield, Blanksby, Ackland, & Allison, 1990; Cronin, McNair, & Marshall, 2000; 2002; Newton et al., 1997).

Studies that have been conducted on upper body movement during various exercise techniques have provided some insight into the specifics of how they influence biomechanical parameters (Cronin et al., 2000; 2002; Newton et al., 1997) and sport skill efficiency (Bloomfield et al., 1990; Crowder, Jolly, Collins, & Johnson, 1993; Newton & McEvoy, 1994; Vossen, Kraemer, Burke, & Vossen, 2000). However, not all of the common variations of upper body exercise training methods (e.g., concentric only, countermovement, and plyometric) have been thoroughly investigated.

Since various exercise methods are used in a wide range of training settings (e.g., rehabilitation clinics, health-fitness facilities, athletic training, training camps, and sport specific clinics), it would be ideal to know which exercises are the most beneficial to intended outcomes for individuals of different abilities, ages, and genders, and for the performance of different sports skills.

Significance of Problem

Since variations in how exercise movement is performed (e.g., range of motion and variation of body position) can cause significant changes in biomechanical parameters, it is important to establish a good understanding of variations in movement with respect to commonly used exercises (Bobbert, Huijing, & van Ingen Sheneau, 1987a; Escamilla et. al., 2001; Lee, Huang, Wang, & Lin, 2001). These biomechanical parameters include peak force, the maximal rate of force development (MRFD), and average peak power output. Although these parameters have been used to compare performances of different types of lower body exercise, they have not been thoroughly applied to the study of various upper body exercises.

In addition the plyometric method is an area where a lack of research exists in regards to upper body exercises (Davies & Matheson, 2001; Knudson, 2001; Wilk et. al., 1993). Plyometric activities sequence movements in a combination that involves the lengthening and shortening of a group of muscles (i.e., stretch shorten cycle (SSC). Plyometric training is often associated with certain strength aspects (e.g., agility, acceleration, speed, force production, and power) that are desirable for athletes to develop for a sport.

Purpose

The purpose of this study was to identify how selected biomechanical parameters (i.e., peak force, MRFD, and average peak power output) differ in the performance of the push-up and medicine ball throw (Figures 1-3) in males using different training methods (i.e., concentric only, countermovement, and plyometric). A secondary goal of this study was to provide information that would contribute to future studies of different populations and specificity of training. In addition, this study was intended to advance scientifically based information that already exists on exercise training methods for the upper body.

Need for Study

At the many fitness and training settings throughout the United States, a broad spectrum of training protocols are used to enhance health, strength, and performance from the general strength of the beginning weight trainer to the sport specific training of the elite athlete. Basic foundational strength training guidelines, aimed at benefiting the health and performance of participants, have been established by research (ACSM, 2002), are taught through certification programs, and are passed on by experienced exercise leaders in various exercise settings. Even though there are some scientifically supported guidelines, numerous professionals train individuals with different and unstudied protocols. These include working the same body parts differently (e.g., variation of training method, position, movement, equipment, intensity a muscle group is worked, and the extent to which muscle groups are developed). Various training methods are used to optimize sports performance and not all of the methods have been thoroughly researched, especially with respect to the upper body. In addition, most of the strength training research has focused on analyzing the lower body and not as many studies have been conducted on upper body training methods. The current study of selected upper body exercise methods was somewhat similar to previous studies of the upper body (Cronin, et al., 2000; 2002; Newton et. al., 1997). Results from the current study are intended to provide comparative biomechanical performance parameters to better understand selected upper body exercises.

The intention of conducting this study is to contribute knowledge to an area of exercise science that has not been thoroughly investigated. Information gained would lend evidence for sport specific training and future studies. This study is also practical and applicable to various movements and training methods used by exercise specialists. Individuals who participated in this study were instructed on proper technique to perform exercises which could be incorporated into their workout regiment. Information gained from this study was provided to the participants. In addition, further publication of the results will provide knowledge that can be used by exercise specialists and researchers.

Hypotheses

The results of this study there were expected to show specific relationships of biomechanical parameters in response to the concentric only, countermovement, and plyometric methods performed between the push-up and medicine ball throw (Figures 1-3). Some of the results expected to occur were:

- Concentric Only (Push-up vs. Medicine Ball Throw)
  - Push-off force generated by college aged males will be greater while performing the push-up versus the medicine ball exercise.
  - MRFD and the average peak power output generated by college aged males will be less while performing the push-up compared to the medicine ball exercise.
- Countermovement (Push-Up vs. Medicine Ball Throw)
  - Push-off force generated by college aged males will be greater while performing the push-up versus medicine ball exercise.
  - MRFD and the average peak power output generated by college aged males will be less while performing the push-up compared to the medicine ball exercise.
- Plyometric (Push-Up vs. Medicine Ball Throw)
  - Peak forces, MRFD, and average peak power output will be similar for both exercises performed by college aged males.

Assumptions

In addition, assumptions were made about biomechanical parameters associated with different exercise methods used to perform the push-up and medicine ball throw.

- Push-off force in the push-up and medicine ball throw will have a hierarchical order with respect to method of exercise (concentric only < countermovement < plyometric) (Bobbert, et al., 1987a; Newton et al., 1997).

- MRFD in the push-up and medicine ball throw will have a hierarchical order with respect to the method of exercise (concentric only < countermovement < plyometric).
- Average peak power output in the push-up and medicine ball throw will have a hierarchical order (concentric only < countermovement < plyometric) (Bobbert, et al., 1987a; Cronin, et al., 2000; Newton et al., 1997).

Definitions of Terms Used

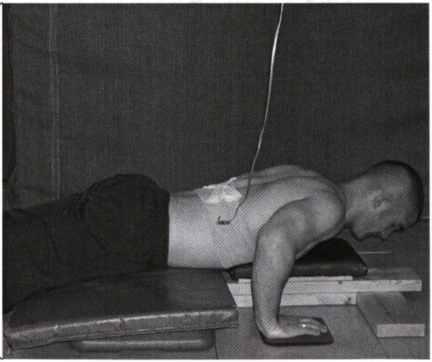
Absolute Strength – the maximal amount of force one is able to exert for a given task.

Amortization Phase – period of time between the eccentric and concentric phases of a countermovement.

Concentric Contraction- movement involving shortening of the muscle where the force of the muscle contraction is greater than resistance (Hall, 1999). Positive work is exhibited with this type of contraction due to the muscle's "moment and angular velocity of the joint being in the same direction" (Winter, 1990). The lower the external resistance is compared to the muscle force the higher the movement velocity the muscle will be able to produce in the concentric contraction. Figure 1 includes the push-up and medicine ball throw exercise

Push-up

Start



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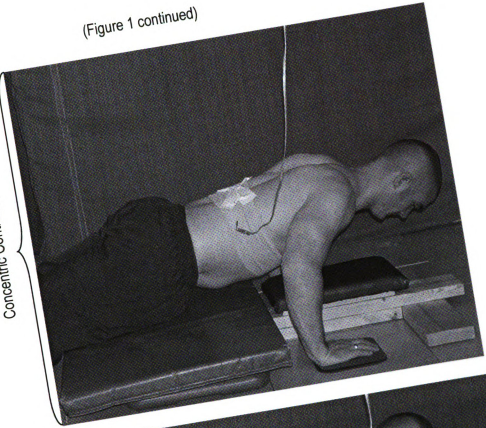
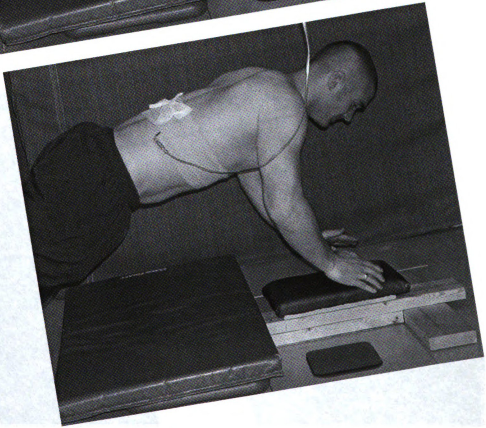
Concentric Contraction





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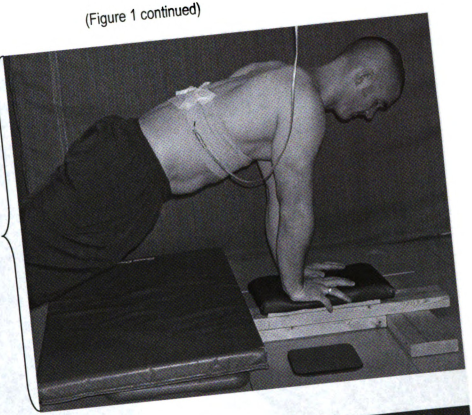
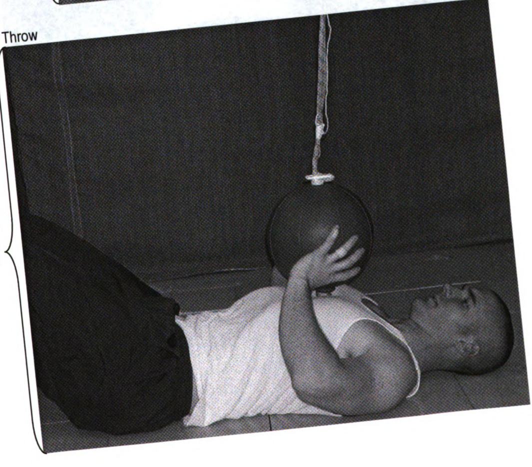


Medicine Ball Throw

Start



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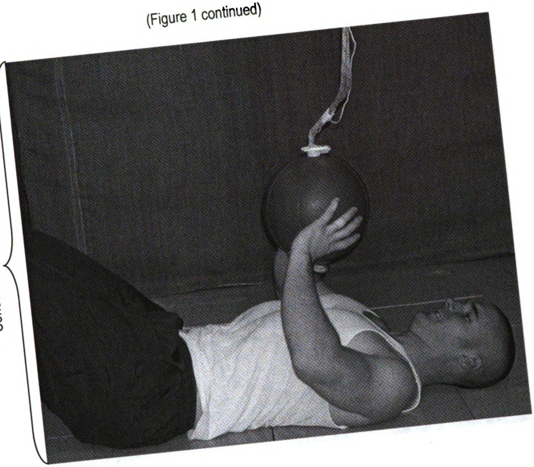

Concentric Contraction

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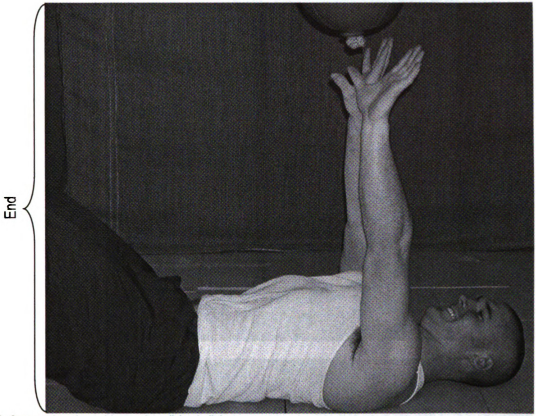
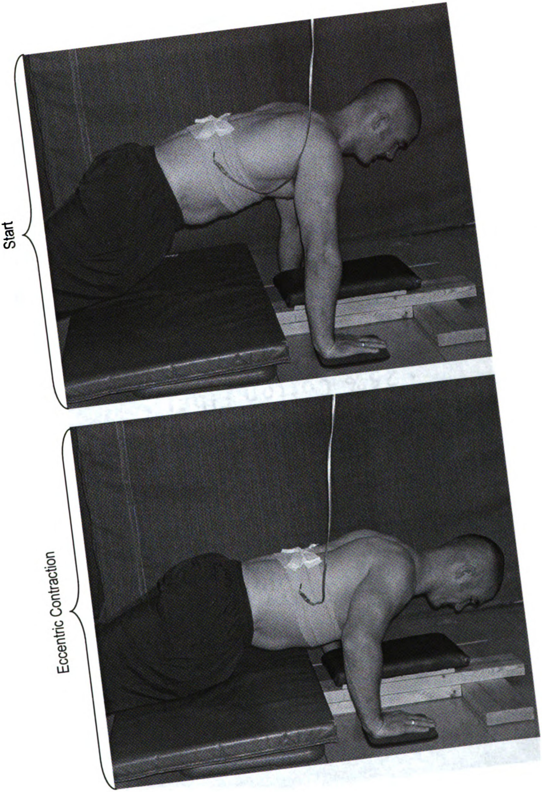


Figure 1. Concentric only push-up and medicine ball throw

Countermovement - an eccentric contraction followed immediately by a concentric contraction of the same muscle group (Figure 2).

Push-up



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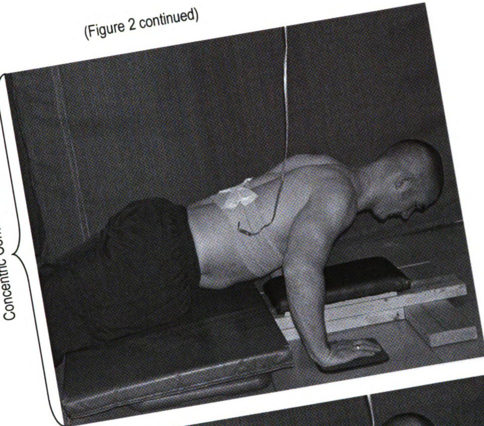
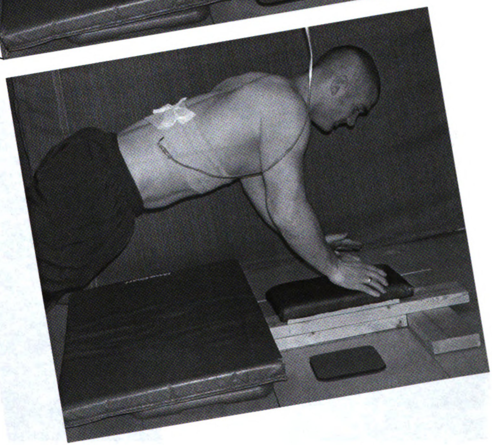
Concentric Contraction





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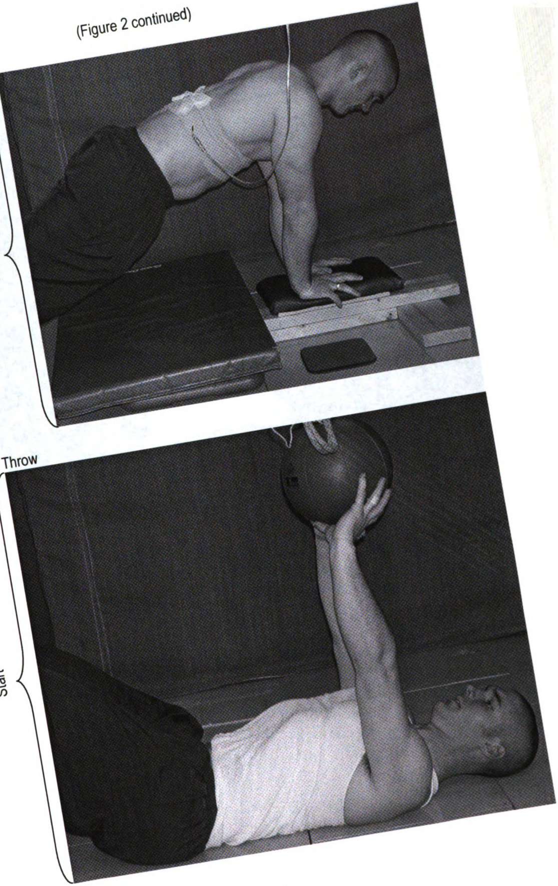
Medicine Ball Throw

Start



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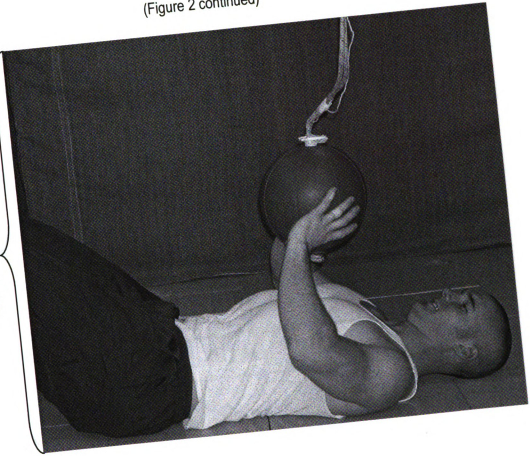

Eccentric Contraction

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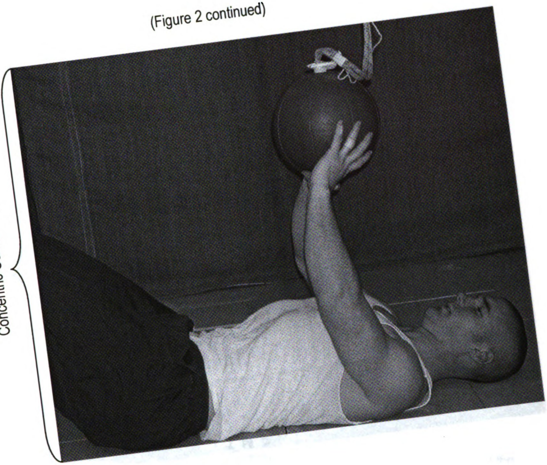
Concentric Contraction



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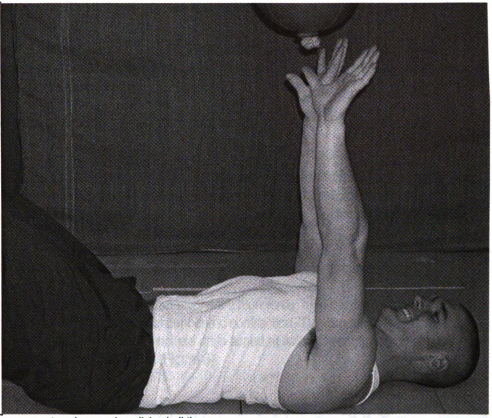


Figure 2. Countermovement push-up and medicine ball throw

Eccentric Contraction - movement involving lengthening of the muscle where the force of the muscle contraction is less than resistance (Hall, 1999).

External Validity - the extent to which research findings are truthful or generalizable to other populations, other times, and other settings.

Force - product of mass and acceleration; force = mass x acceleration.

History - anything that happens during the period of time between one measure of a dependent variable and a subsequent measure of the same dependent variable.

Internal Validity - the quality of the research design; the ability to claim that difference (if any) are caused by the independent variable rather than an intervening, extraneous, or attribute variable.

Isokinetic Contraction - muscular shortening in which the angular velocity about a joint is kept constant by an external torque (typically generated by an isokinetic dynamometer) equal and opposite to the internal torque (generated by the contracting muscle).

Isokinetic Dynamometer - motorized equipment designed to provide an accommodating resistance to the concentric torque generated by the contraction of muscles.

Isometric Contraction - external resistance equal to the internal force produced by contracting muscle causing no movement to occur about a joint and no change in length of contracting muscle.

Isotonic Contraction – most common type of muscle contraction in which a muscle or group of muscles moves a specified load through a range with varied force of muscular contraction and varied angular velocity of movement.

Maturation – progress of a biological system toward a mature state that influences a dependent variable.

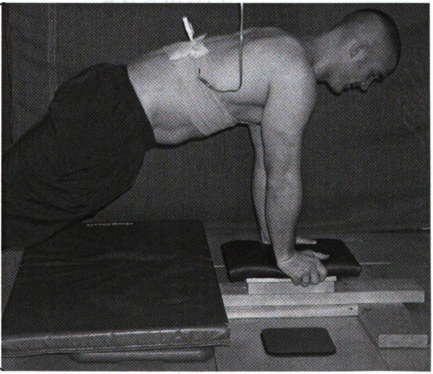
Maximal Rate of Force Development (MRFD) - the greatest amount of force that can be produced in the shortest amount of time, represented by the steepest slope of the force-time curve. ("The ability of the neuromuscular system to develop high action velocities" (Schmidtbleicher & Komi, 1992).

Multiple Treatment Threat - one treatment influencing the effects of another treatment.

Plyometric - a type of countermovement that involves a high force, high speed, and low amplitude eccentric contraction followed by a forceful concentric contraction. This process relies on the stretch shorten cycle (SSC). Plyometrics include drills aimed at linking strength with speed of movement to produce power (Chu, 1998) (Figure 3).

Push-up

Start



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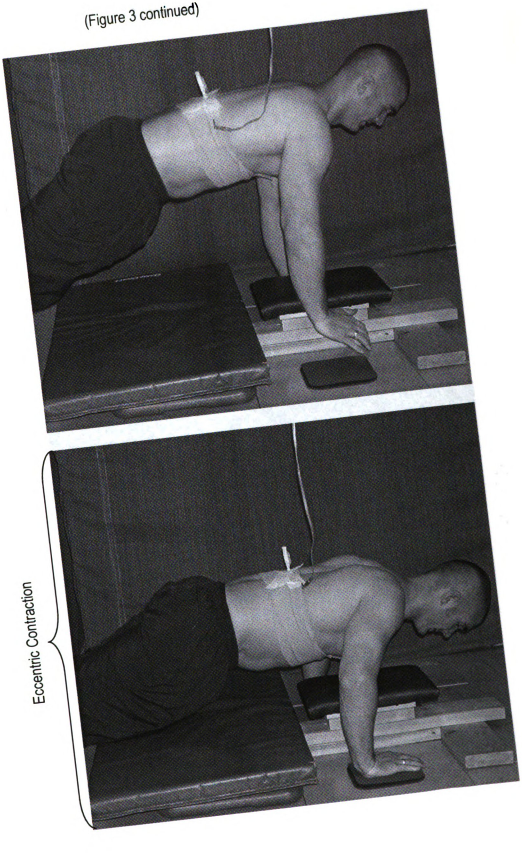

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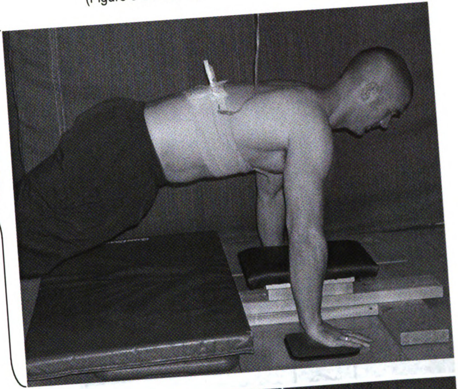
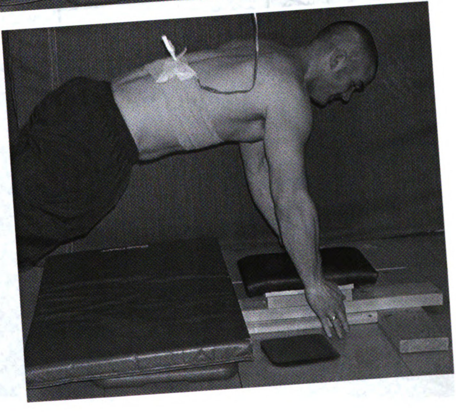
Concentric Contraction





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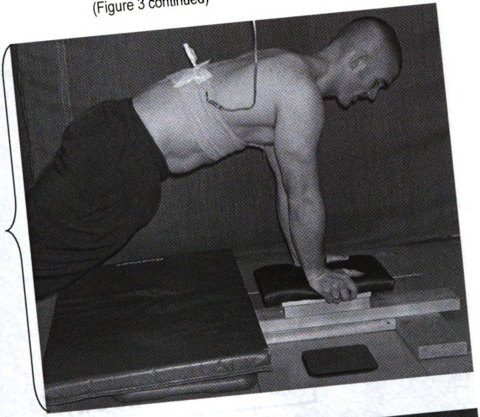
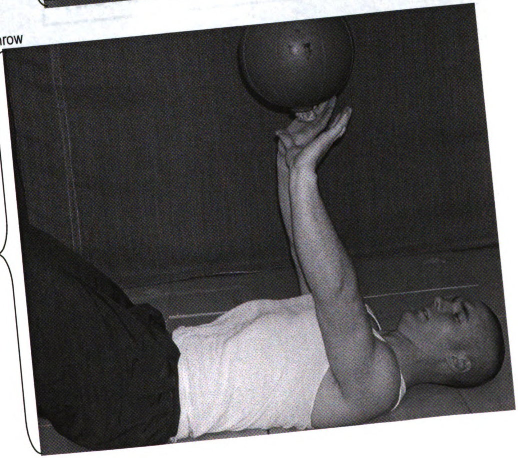
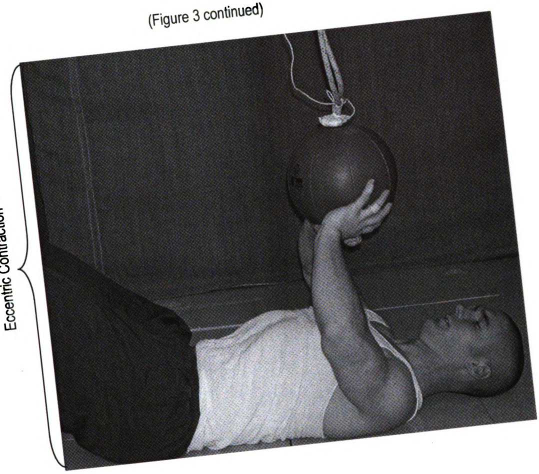


Medicine Ball Throw

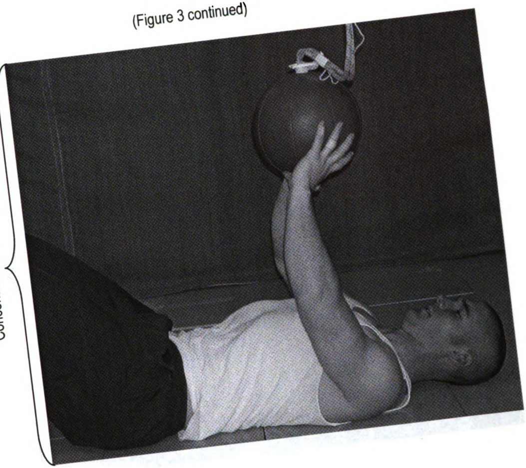
Start



(Figure 3 continued)



(Figure 3 continued)



Concentric Contraction

(Figure 3 continued)

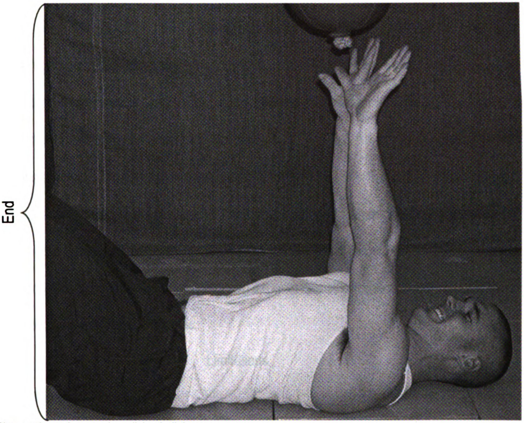


Figure 3. Plyometric push-up and medicine ball throw

Relative Strength – ones maximum amount of strength in a task that made in comparison to their body weight

Repetition Maximum (RM) – exercise that an individual can perform no more than a designated number of repetitions under the load imposed (e.g., 1RM is an exercise that an individual can only perform one time under the load imposed).

Sport Skill Efficiency - ability to enhance the performance of a skill within a sport as a result of training effectively.

Stretch Shorten Cycle (SSC) - eccentric movement prior to concentric movement that utilizes muscle elasticity and muscle spindle response during the eccentric phase of an exercise to facilitate force of muscle contraction during the concentric phase.

Training Methods – different muscle contraction patterns (e.g., isokinetic, isometric, isotonic, concentric only, countermovement, plyometric) used in exercise regimes.

Training Specificity - enhancement of performance resulting from a training regime in which the movement pattern or exercise is similar or identical to the outcome to be evaluated.

Variations in Movement - alternative motions that may occur in the performance of an exercise (e.g., speed of movement, range of motion, positioning of body parts).

Assumptions

Assumptions of this study include:

- Participants were healthy and trained in a resistance program for a minimum 6 weeks on a consistent basis immediately prior to the study.
- Participants gave their maximal effort during exercises.
- Participants exerted equal amounts of force from each hand when performing the push-up on the force platform and when performing the medicine ball throw.
- The accelerometer gave a true reading and experienced little rotation during the push-up and medicine ball throw exercises.

Limitations

Limitations of this study include:

- The sample size for this study was 17 participants.
- Take-off velocity in the performance of the push-up and medicine ball throw was indirectly measured through the use of an accelerometer.
- The vertical ground reaction force was measured in the push-up exercise via single force platform located under the right hand.

CHAPTER 2
REVIEW OF LITERATURE

Selected pertinent research on exercise training from the previous 30 years was used in this review. An examination was made of different types of exercise methods (i.e., concentric only, countermovement, and plyometric) and the training duration, frequency, and intensity on post training results. In addition, biomechanical parameter comparisons of movement and skill performance were made between the different types of exercise methods. Even though the upper body is the focus of this study most of the information available is from studies of the lower body. After comparisons are made, biomechanical parameters (i.e., force, MRFD, and power output) will be discussed on how they are influenced by the different exercise methods. Finally, implications will be made from pertinent literature sources available for this study.

Concentric Only Exercise Method

There are a number of studies involving concentric only exercises. However, concentric only exercises are rarely used at training settings. Articles that review the concentric only training method show how participants who trained at various constant angular velocities have different training effects. Training regiments used in the various concentric only exercises will be identified in this review of literature.

Training Studies of Concentric Only Exercises

Studies of concentric isokinetic contractions have primarily focused on the ability to produce greater amounts of torque in knee flexion and extension in association with training at different constant angular velocities (Caiozzo, Perrine, & Edgerton, 1981; Coyle et. al., 1981; Kanehisa & Miyashita, 1983; Prevost, Nelson, & Maraj, 1999). These studies tend to show training specificity. Biomechanical properties of various exercises were influenced by the force and speed in which the muscles contract. For example, training the knee extensors at relatively high angular velocities (i.e., 4.19, 4.71, and 5.24 rad/s) improved torque production the most at faster velocities (Caiozzo, et al., 1981; Coyle et al., 1981; Kanehisa & Miyashita, 1983; Prevost, et al., 1999). Similarly, slower angular velocity training (i.e., 0.52, 1.04, 1.05, and 1.68 rad/s) of the knee extensors improved post training torque production the most at the slower tested velocities and post training torque production more than the higher angular velocity training through out the range of exercise velocities tested (Caiozzo, et al., 1981; Coyle et. al., 1981; Kanehisa & Miyashita, 1983; Prevost, et al., 1999). In another study using an isokinetic dynamometer, Behm and Sale (1993) trained participants' dorsiflexors. Participants trained one ankle with fast force developing isometric dorsiflexions set at 0 rad/s and the other ankle with fast isokinetic dorsiflexions set at 5.23 rad/s. The post test training results of their study for both ankles were similar for peak force and rate of force development. Their conclusion was training movement speed might not be as important as training the rate in which force is developed. The results from this study do not support training specificity.

Guidelines for Concentric Only Exercises

Studies which incorporated the isokinetic dynamometer as the method of training varied in their use of the number of sets and repetitions in which the training was performed (Behm & Sale, 1993; Caiozzo et al., 1981; Coyle et. al., 1981; Kanehisa & Miyashita, 1983; Prevost, et al., 1999), making it difficult to compare and draw generalizations across studies. Typically the number of sets performed during training ranged from two to five, and the number of repetitions per set ranged from 6-50. Rest between sets also varied from 1-3 min (Behm & Sale, 1993; Kanehisa & Miyashita, 1983; Prevost, et al., 1999). Studies from the literature review used training frequencies of 2-6 days per week. Duration of the training in the isokinetic studies ranged from 2 days to 16 weeks. Participants in these studies (Caiozzo, et al., 1981; Coyle et. al., 1981; Kanehisa & Miyashita, 1983; Prevost, et al., 1999) ranged from 19-38 years of age with the majority of participants in their lower

20's. Age was not mentioned as being significant to the outcome of the various studies or determined to be significantly different between groups. Even though most of the studies were conducted on males, studies including both male and female participants reported no difference between genders in post test strength gains (Behm & Sale, 1993; Caiozzo, et al., 1981).

Summary of the Concentric Only Exercise Method

Unfortunately, because isokinetic dynamometers are not available at most training facilities and are typically used in rehabilitation, their use in strength training is not practical. More recent studies have used training with free weights to evaluate concentric contractions in comparison to the countermovement exercise (Cronin, et al., 2000; 2002; Newton et. al., 1997). However, no literature was found in which the body, free weight, or machine weight was used for training with concentric only movements, to explore the effects of training. Appendix A provides a summary of the concentric only review of literature.

Countermovement Exercise Method

The majority of strength training studies involve countermovement exercises using resistance created by the body, free weight, or machine weight. Countermovement training is typically performed in most training facilities. However, there is a paucity of countermovement studies of the upper body that are available to be highlighted in this review of literature. Information reviewed on countermovement exercise includes the types of upper and lower body exercise used in training, provides basic strength training guidelines, examines the training effect of speed of movement and load has on the lower and upper body, and examines what differences were found between gender and race.

Studies of Upper Body Countermovement Exercises

Studies of upper body countermovement exercises focus on the chest (push-ups, bench press, and chest flies), back (lat-pull down), shoulder (overhead press and behind the head press), and arm (bicep curl and triceps press) (Blackard, Jensen, & Ebben, 1999; Bloomfield, et al., 1991; Fields, et al., 1997; Jones, Hunter, Gleisig, Escamilla, & Lemak, 1999; Newton, Kraemer, Hakkinen, Humphries, & Murphy, 1996). Testing of countermovement exercises of the upper body in previous studies had participants perform three trials with a 2-5 min rest between sets and 2-4 days before retesting (Blackard, et al., 1999; Fields, et al., 1997; Newton, et al., 1996). Usually an orientation session was given prior to testing to familiarize subjects with testing and the following session was used to initiate data collection.

Guidelines for Countermovement Exercises

The foundation of resistance training is stated by governing bodies such as the American College of Sports Medicine (ACSM) and the National Strength and Conditioning Association (NSCA) as part of their certification processes. General guidelines vary little between these two organizations. Therefore, this review will be limited to the inclusion of the guidelines stated by NSCA (Baechle & Earle, 2000). Usually the same number of sets and repetitions for both the upper and lower body are used during training.

- If the objective is to develop strength, two to six sets of one to six repetitions at an intensity greater than 85% of maximal strength with a 2-5 min rest between sets is recommended.
- For developing power, three to five sets with one to five repetitions at 75-90% of maximal strength taking 2-5 min of rest between sets is recommended.
- To enhance muscle size, three to six sets with 6-12 repetitions at 67-85% maximal strength with 30-90 s of rest between sets is recommended.
- For endurance two to three sets of 12 or more repetitions at less than 67% of maximal strength with less than a 30 s rest between sets is recommended.

- Duration of the countermovement training should last 7-9 weeks, which has been reported to be a sufficient amount of time for physiological changes to occur, especially in sedentary individuals (Wilmore & Costill, 1999).

Varying training loads cause different "acute metabolic, hormonal, neural and cardiovascular responses" (ACSM, 2002). Variation in force of muscle contraction has been attributed to the muscle's neural adaptations, cross-sectional area, pennation of fibers, length, contraction velocity, type of action, strength to mass ratio, as well as the body size, joint angle, and joint angular velocity (ACSM, 2002; Baechle & Earle, 2000; Wilmore & Costill, 1999).

Speed of Movement and Load

The following studies examine the effects manipulation of frequency of contraction and magnitude of resistance (load) has on sport or skill performance. Training studies of the lower body have used various speeds of motion in either the eccentric and/or the concentric phase of the countermovement. The speed of motion during training is affected by the load imposed or the pace that is set by the investigators for the participants. A study by Harris, et al. (2000) investigated the effect of load on training collegiate football players. Three groups trained at different percentages of their maximal strength using the same number of sets and repetitions. The groups consisted of a high power group (30-45% 1RM), high force group (80% 1RM), and combination group, which used both methods of training. All groups performed strength, skill, and sports tests pre- and post training. The high power group improved more in the skill and sports performance test where the high force group's improvement was demonstrated more in the strength tests. The combination group improved in more skill and sports performance tests than the other groups. Another investigation by Blazevich and Jenkins (2002) found no substantial difference in the significant improvements in strength or 20 m acceleration time between fast (30-50% 1RM) or slow (70-90% 1RM) training in the concentric phase for trained collegiate sprinters. Other studies with non-resistant trained participants have used squat exercises and modified tempo between groups, using similar repetitions and sets for training (Morrissey, et al., 1998; Young & Bilby, 1993). In these studies it was found that the fast and slow training groups improved significantly in force, MRFD, and power output. There were differences noted in the extent that biomechanical variables were increased between the fast and slow training groups.

Results from these studies become less clear when looking at what implications they have on a type of sport performance (i.e., vertical or long jump). Results of these studies indicate that both types of training are can improve jumping ability. Limitations of these studies could include not allowing a full range of motion during the concentric phase, which has been shown to affect biomechanical variables (Newton, et al., 1996). Also in the two mentioned studies, groups performing the squat faster had to develop force faster in the concentric movement to keep up with the set training pace. Behm and Sale (1993) stated in their study that the attempt to produce ballistic movements might be more important to improving the speed of movement than training at high speeds. Another limitation was that the results from these studies could have varied due to the use of non-resistant trained participants. With non-trained participants training effects are going to have more variation compared to a more homogenous resistant trained population.

There are few studies of the upper body that have investigated the effect of training. Bloomfield, et al. (1990) investigated whether anthropometric or upper body training had the biggest impact on the ability of experienced water polo players to throw overhand at high velocities. Results from this study indicated that limb length and body width were significantly related to throwing velocity compared to the resistance training which did not produce any significant changes. However, the number of repetitions and sets used in the training protocol were more designed to develop muscle endurance and size than improve strength or power. Jones, et al., (1999) studied football players in an off-season 14 week training program using either conventional countermovement training or countermovement training with higher concentric accelerations. Results from this study indicate that using higher concentric accelerations in the countermovement increased strength and power performance (i.e., distance of a medicine ball throw) to a greater extent than traditional countermovement training.

Gender and Race

Countermovement exercises are effective in producing physiological and biomechanical adaptations in males and females in non-resistance and resistance trained individuals. Two studies were reviewed to see if the training effects and biomechanical variables were different by gender and race. One study (Staron et. al., 1994) involved post training comparisons of the lower extremities between men and women of similar age and background. Some differences were found in regards to the rate at which men or women improved strength on the leg extension and leg press. But, both men and women improved strength significantly and had similar changes in muscle adaptation during the beginnings of strength training. Differences did occur in regard to hormone levels during the initial phase of training. Testosterone levels increased and cortisol levels were lower in men in comparison to women.

In 1997, Fields, et al. observed the differences between race on muscle strength and power. The two groups consisted of African Americans and Caucasian Americans performing maximal strength and power lifts for the bench press and leg press exercise. In comparison of maximal strength no differences existed between either race. The ratio of strength between the upper and lower body was slightly higher for the African American group than the Caucasian group. No racial differences existed for the upper or lower extremity muscles between the strength-power relationships.

Summary of Countermovement Exercise Method

The countermovement is often used with many types of exercises and strength training guidelines have been established for this type of training. However the effects of training are shown to vary according to study and there are few upper body studies conducted. Refer to Appendix A for the summary of the countermovement review. Another area of interest for further investigation is upper body is plyometrics exercises. Note that plyometric exercises incorporate a countermovement. Plyometrics will be discussed next.

Plyometrics

Plyometrics are used in rehabilitation, sport activities, and training. Performing upper body plyometric training may enhance the upper body's ability to perform explosive movements used in sports such as golf, softball, tennis, football, track, and baseball (Baechle & Earle, 2000). In training, plyometrics are used to give individuals an advantage for developing specific skill performance and explosiveness. However, most studies of plyometric exercise involve the lower body (Bobbert, Huijing, & van Ingen Schenau, 1987b; Hakkinen, Komi, & Alen, 1985; Hewett, Stroupe, Nance, & Noyes, 1995; Matavulj, Kukolj, Ugarkovic, Tihanyi, & Jaric, 2001; Young, Wilson, & Byrne, 1999a; 1999b). Because of the lack of upper body research reported for plyometrics, most information included in this review of literature will be of the lower body. This review covers the neuromuscular system during plyometrics exercise, guidelines for the types of exercises used for plyometric training, and biomechanical and training studies that have used plyometric exercises.

Neuromuscular Response to Plyometrics

Plyometrics rely on an eccentric-concentric sequence of movement, sometimes referred to as the stretch shortening cycle (SSC). The SSC consists of three phases of muscle contraction that occur in the following order: eccentric, amortization, and concentric. During the eccentric phase of contraction, muscle lengthening and rate of length change stimulate the muscles and nerves.

During this phase, energy is absorbed into the muscles due to their elasticity. At the same time, the stretch and rate of stretch of the muscle stimulates muscle spindles. The duration and amplitude of the eccentric phase during plyometric exercise determines the magnitude of biomechanical variables in the initial concentric phase. Larger amplitudes of movement in the eccentric phase decrease the ability of biomechanical variables to be enhanced during the initial part of the concentric phase. A longer duration and amplitude attenuate the nerve response and dissipate the stored energy of the muscles. At the end of the eccentric phase, a quick explosive translation is made in the concentric phase. The change in direction of movement is called the amortization phase, which identifies the change in muscle contraction from eccentric to concentric.

Guidelines for Plyometric Exercises

Specific recommendations for the number of repetitions and sets for plyometric exercises are few (Davies & Matheson, 2001). Chu (1998), who has worked with the conditioning of many elite athletes in different sports, has set some guidelines and recommendations for plyometric training. He divided up plyometrics into five types of exercises: jumps in place, standing jumps, multiple jumps and hops, box drills, and depth jumps. The intensity level of plyometric exercises has a general rating of low to high in the previously listed order of exercises. The amount of work done when performing plyometrics depends on the type of plyometric activities. Typical plyometric activities use the number of foot contacts per session to estimate the amount of work done (Chu, 1998). The number of foot contacts can vary from 60-450 per training session depending on the experience level of the athlete and the training season (Chu, 1998). From the literature review 24-30 jumps were performed 3 days a week (Matavulj, et al., 2001; Young, et al., 1999a). Another way to estimate the amount of work done in certain plyometric exercises, called bounding (similar to skipping or exaggerated running movements), is through distance. An exercise work to rest time interval ratio of 1:5 or 1:10 in time is recommended when performing plyometrics. Rest periods from the literature review from plyometric training studies use a 3-5 min rest between exercise trials. Knudson's study (2001) used a 30 s rest between each plyometric movement when testing the upper body's biomechanical variables. Hrysomallis and Kidgell's study (2001) used a 3 min rest period but used more repetitions in a set prior to testing.

Biomechanical and Training Studies of Plyometric Exercises

Studies of lower body plyometric training usually involved a combination of types of plyometric exercises (Hakkinen, et al., 1985; Hewett, et al., 1996; Matavulj, et al., 2001; Young, et al., 1999a). Plyometric training has been shown to improve the rate of force development (Matavulj, et al., 2001; Hakkinen, et al., 1985), force production, power output, and the ability to jump higher (Hakkinen, et al., 1985; Hewett, et al., 1996; Matavulj, et al., 2001; Young, et al., 1999a). This improvement in biomechanical variables is important when correcting for muscle imbalance (Hewett, et al., 1996). Plyometric training has also helped to decrease the impact force individuals encounter when landing from jumps as well as decrease the amount of unwanted knee movement (Hewett, et al., 1996). Biomechanical studies that test the performance of the lower body are primarily from plyometric depth jumps (Bobbert, et al., 1987b; Young, et al., 1999b). Plyometric exercises that involve depth jumps indicate that higher falling heights increase the amount of negative work and ground reaction force encountered (Bobbert, et al., 1987b). Yet increasing the height of the fall, to a certain extent, has been shown to augment concentric biomechanical variables (Bobbert, et al., 1987b).

Summary of Plyometric Exercise Method

Information from the plyometric review is useful to understanding how the neuromuscular mechanisms work, providing guidelines to consider with plyometric training, and describing the benefits and observations of plyometric training. Similar to the concentric only and countermovement exercise methods discussed previously, there is little information in regards to upper body plyometric exercise. Even exercise professionals have stated that there is a lack of upper body plyometric studies (Davies & Matheson, 2001; Knudson, 2001; Wilk et. al., 1993). Refer to Appendix A for a summary of the plyometric exercise method.

Comparisons of Exercise Methods

The final part of this review will compare the previously reviewed concentric only, countermovement, and plyometric methods. Most research on exercise testing or training compares the effects of using different exercise methods on biomechanical variables. Using different exercise methods will cause the results of biomechanical parameters to differ (Lee, et al., 2001). In addition this exercise method review will compare biomechanical parameters between genders.

Comparison of Biomechanical Performance Parameters Among Exercise Methods

Results from testing the performance of the upper or lower body during a concentric only exercise show the measured performance (i.e., jumping height, force production, and power output) to be lower than for countermovement or plyometric exercises (Cronin, et al., 2000; Komi & Bosco, 1978; Newton et. al., 1997). Since the concentric only method has not been shown to augment sport skill variables or biomechanical parameters to the same extent as the countermovement or plyometric methods, it is usually overlooked in research and training. Cronin, et al. (2002) identified the concentric only average power output as the "best predictor for SSC power production" in the bench press. They concluded that there may be merit in training the ability to develop concentric force. There were no studies reviewed that compared the effects of training the concentric only method to the countermovement or plyometric method.

Based on testing of the lower body, countermovement and plyometric exercises differed in biomechanical output parameters. Typically plyometric movements produce higher values for biomechanical variables than those for countermovement. Participants' centers of gravity were shown to achieve greater maximum height with plyometric (depth) jumps in comparison to countermovement jumps (Komi & Bosco, 1978). Likewise during the countermovement jumps, the participants' centers of gravity achieved greater maximum height in comparison to the concentric only jumps. A later study by Bobbert, et al. (1987a) indicated higher force production, moment, and power output in the plyometric jumps compared to countermovement jumps. However, the jumping heights and take-off velocities were lower during plyometric jumps compared to countermovement jumps.

Studies comparing the effects of plyometric and countermovement training typically are in agreement but the extent of agreement varies. As a result of lower body exercises, both methods of training have demonstrated the ability to improve the maximum height participants are able to jump (Delecluse et. al., 1994; Newton, et al., 1999; Wilson, Newton, Murphy, & Humphries, 1993). Upon further examination in the studies by Newton, et al. (1999) and Delecluse, et al. (1994), only the plyometric training groups exhibited a change in jumping performance; whereas, in Wilson, et al. (1993) all groups (i.e., those that used traditional training, plyometric training, or power training) had this experience. Results of these studies also showed that participants had greater gains in strength during countermovement training. In addition, the MRFD improved with the countermovement and plyometric method of training when performing isometric tests (Wilson, et al., 1993) and only with the plyometric training when performing the squat jump (Newton, et al., 1999). Other variables influenced by plyometric training include significant improvements in power, velocity, displacement for the plyometric power squat, force production of the squat jump, and force and power output during the countermovement jump (Newton, et al., 1999). In the same study the countermovement group improved the power, velocity, and displacement of the bar for the plyometric power squat only at 30% 1RM, the velocity of the countermovement jump, and peak force and power output during the heaviest loaded squat jump (an additional 40 kg to participant's body weight). Other interesting results of plyometric training include improvements in initial acceleration and a decrease in 100 m time (Delecluse et. al., 1994), decrease in ground contact time, and a higher flight to foot contact ratio with plyometric training (Newton, et al., 1999).

Upper body studies conducted by Crowder, et al. (1993); Newton and McEvoy (1994); and Vossen, et al. (2000) explore the differences between the plyometric and countermovement methods. Crowder's, et al. study (1993) conducted on the effects of plyometric push-ups in comparison to traditional push-ups (countermovement) disclosed that plyometric training improved power production significantly and to a greater extent than did countermovement training. Newton and McEvoy's study (1994) contrasted the effects of plyometric medicine ball overhead throws and the traditional countermovement bench press on the upper body's strength and capability to improve the throwing velocity of a baseball. Throwing velocity was increased considerably by traditional countermovement weight training compared to plyometric training. Both types of training significantly improved strength. In Vossen's et al. study (2000) the distance a medicine ball was thrown improved in both plyometric and traditional push-up training, but the plyometric group improved to a greater extent. The traditional group's improvements were greater in chest strength than in the plyometric group.

Gender Comparison of Biomechanical Performance Parameters on Training Methods

Some literature was found that compared the influence of exercise methods (i.e., concentric only, countermovement, and plyometric) between men and women. Men jumped higher than women for all three jumping methods (Komi & Bosco, 1978). But, women were more efficient in transferring the elastic energy of the eccentric phase to the concentric phase during the countermovement jumps. However, Cronin et al. (2002) found no significant difference between gender when examining the predictors of power absorption and production for the concentric only and countermovement bench press.

Summary of Exercise Methods

Even though the results of studies that have made comparisons between the concentric only, countermovement, and plyometric exercise methods are not consistent, some general conclusions can be made from the literature. An eccentric phase performed before a concentric phase enhances potential performance of the concentric phase (i.e., jumping height, force production, and power output) compared to the concentric only method. Strength is improved more with countermovement than with comparable plyometric training. Usually the plyometric method increases biomechanical parameters (i.e., higher force production, power output, and moment) and explosive performances (i.e. jumps, sprints, and medicine ball throws) to a greater extent than a comparable training using a countermovement method. See Appendix A.

Measurement of Pertinent Biomechanical Parameters

Since the objective of this study was to compare selected biomechanical output variables (force output, MRFD, and power output) in the push-up and medicine ball throw under similar exercise methods (concentric only, countermovement, and plyometric), studies that incorporated similar variables were reviewed for the methods they employed. The magnitude of biomechanical variables has been shown to have relationships to the level of sports performance (ACSM, 2002; Garhammer, 1985; Kanehisa & Miyashita, 1983; Morrissey, Harman, & Johnson, 1995; Schmidtbleicher & Komi, 1992; Stone, Byrd, Tew, & Wood, 1980; & Young & Bilby, 1993). Some of these variables, relating to the current study, include peak force, MRFD, and average peak power output. Typically, when these biomechanical variables have been incorporated in research on physical performance, they have been measured via force platforms and strain gauges. The following studies provide examples of how these biomechanical variables have been measured. In addition, these studies have provided a basis for selecting methods to measure the peak force, MRFD, and average peak power output in the current study.

Peak Force

Previous studies of various exercises performed via different exercise methods have used force platforms sampling at frequencies from 500-1000 Hz during fast explosive movements. (Baca, 1999; Bobbert, et al., 1987a; Newton, et al., 1996). Since the push-up and medicine ball throw were done in an explosive manner and the force platform had the ability to be sample at a high frequency, 1000 Hz was selected for recording during exercise trials in the current study. During the orientation session, 100 Hz was selected for the sampling frequency to record the participants' weight.

When comparing how precise the various ways of using force platforms and other equipment to simultaneously record biomechanical parameters during a jumping exercise, Baca (1999) concluded that the double force platform was the "reference method" for analyzing drop jumps. However, when comparing the results of recording with only one force platform (i.e., one force platform under both feet) to the use of a double force platform (i.e., one force platform under each foot), results were similar. But, the use of one force platform was not considered practical in this study due to the size of the force platform available and the space needed for the drop jump. Only one force platform was used to record force data of the push-up and medicine ball throw exercises in the current study. It was assumed that the force-time history experienced by right hand in the push-up was similar to that experienced by the left hand.

Maximal Rate of Force Development

The maximal rate of force development (MRFD) has been determined directly from computer readouts of the force applied to a force platform. Two methods have been used to determine the MRFD. Kovacs, et al., (1999) measured the rate of force development (RFD) by "dividing peak force (F_{V1} and F_{V2}) by the time elapsed from the onset of increasing force to the peak." The RFD can also be calculated in smaller time intervals (e.g., 5 ms) that allow one to determine the maximal rate at which the force is being developed (Young & Behm 2003). From Young and Behm's study (2003) the recordings of force were taken over a period time in which the force levels were rising during the exercise movement. In the current study a similar method was used to that of Young and Behm's study (2003). Since participants were performing these exercises explosively and the sampling frequency was at 1000 Hz during these exercises, small intervals of time (5 ms) were used to evaluate the rate of change in the force curves. This method was selected to identify the sudden changes in the magnitude of force application.

Average Peak Power Output

No information was found in the literature that used an accelerometer in conjunction with a force platform to determine average peak power output. Power is a product of force and velocity. In the current study, velocity was determined through the use of an accelerometer by dividing acceleration values by small intervals of time (5 ms). Acceleration values represent the change in velocity over a period of time. In comparable methods of exercise the acceleration values from the push-up exercise (accelerometer attached to the sternum of the chest) were expected to be less than the acceleration values of the medicine ball (accelerometer attached to a plastic mount inserted into the top of the ball) since the skin is a more pliable material and the chest is more massive in comparison to the medicine ball (Nigg & Herzog, 1994). Note that the outputs from the accelerometer and force platform were synchronized during the test and retest sessions. Synchronizing these instruments allowed both force and acceleration values to be evaluated simultaneously during the same time period providing a means to calculate average peak power output.

Implications of the Literature Review for the Current Study

How biomechanical variables are collected and the interest in these variables to exercise specialists and researchers has set a foundation for examining how those variables compare between exercise methods. The literature review has also helped to confirm that there is a lack of scientifically based biomechanical information on exercise methods used for the upper body, especially in relation to plyometric exercises. Therefore the exercises tested in this study are the push-up and medicine ball throw performed with the concentric only, countermovement, and plyometric method. The following paragraphs will state similar protocols from past studies and how those considerations were used for the current study.

From the literature, when biomechanical parameters are measured for an exercise, a comparison is made between variations of exercise methods (i.e., concentric only, countermovement, and plyometric). When using the plyometric method, a general recommendation from the NSCA is that participants should have a foundational base of strength through resistance training prior to participation. For studies of upper body plyometric repetitions, two to three trials have been used per testing session with a rest period of 5–30 s with 1-3 min between different types of exercise methods with 2-4 days of recovery. (Blackard, et al., 1999; Cronin, et al., 2000; 2002; Fields, et al., 1997; Knudson, 2001; Newton, et al., 1996, Newton et. al., 1997; Vossen, et al., 2000; Young, et al., 1999b).

Since upper body exercises need to be further researched, comparisons of the biomechanical parameters in performing the push-up and medicine ball throw (Figures 1-3) were selected to be study. For the current study, two to three trials were used to collect information on the exercise methods selected and data was collected on 2 days separated by a 48 hour rest period. Two days were selected, by the investigator and participant, to test and retest participants and to have a total of five trials per each exercise method. Thirty seconds of rest was given between each trial and 2 min of rest between the push-up and medicine ball throw exercises.

The previously mentioned implications established a foundation to test if significant differences in kinetic and kinematic parameters are present when using various upper body exercise methods. Modifying the exercise method to differentiate biomechanical parameters was used to establish hypotheses.

CHAPTER 3
METHODS

This chapter describes the methods that were used in this study and their purposes. For these methods information is presented on their relationships to the research design, participants, exercise conditions, instrumentation, data collection procedures and data analysis. In addition, the purposes for selecting the methods used in this study are provided.

Research Design

This was a descriptive, non-experimental, cross sectional study of biomechanical performance parameters under different conditions of upper body exercise. There were two independent variables identified in this study. The two independent variables were based on methods (i.e., concentric only, countermovement, and plyometric) and the two upper body exercises (i.e., push-up and medicine ball throw). A comparison was made on how the same method used for the two exercises (i.e., concentric push-up versus concentric medicine ball throw, countermovement push-up versus countermovement medicine ball throw, and plyometric push-up versus plyometric medicine ball throw) influenced the dependent variables (i.e., biomechanical parameters). The dependent variables included the peak force, MRFD and average peak power output.

Each participant completed an orientation session, testing session, and retesting session. Participants were randomly assigned to two groups. The order of task presentation was counterbalanced across the two groups during the testing sessions as illustrated in Table 1.

Table 1. Procedures for the Testing Sessions for Group 1 and Group 2

Group 1	Group 2
Warm-up	Warm-up
Medicine Ball Throw	Push-ups
• Concentric Only	• Concentric Only
• Countermovement	• Countermovement
• Plyometric	• Plyometric
Medicine Ball Throw	Push-ups
• Concentric Only	• Concentric Only
• Countermovement	• Countermovement
• Plyometric	• Plyometric
Stretching	Stretching

The counterbalanced order of task presentation and the random assignment of participants to groups was a strength of the research design because it minimized group threats and interaction effects of selection bias and experimental treatment. Other efforts to strengthen the research design and minimize threats to internal and external validity were calibration of instruments before sessions and familiarization of participants to the testing procedures, exercises, and environment. A homogenous group, males 18-30 years of age who were healthy and currently participating in resistance training, were selected to minimize history and maturation. In addition, not allowing participants to view another participant's performance addressed on stage effects. Two testers were used in measurement, instruction, and motivation to account for expectancy. Participants also performed the exercises in a standard randomized order which reduced the threat of reactive or interactive affects of testing. Providing a familiarization session, having the participants perform methods in a random order, and preventing participants from observing others perform was a strength because it minimized reactive effects of experimental setting. Another strength of the study was providing adequate rest (48 hours between sessions, 1-2 min between conditions, and 15-30 s between trials), having a standard randomized order of exercises, and using a different number of trials with each exercise per testing session which minimized multiple treatment threat (Table 1). In this study there was no pre testing, intervention, and post testing.

Participants

Selection Criteria

Four criteria were used to determine eligibility for participation in this study:

- Men 18-30 years of age insured that growth and development was complete or nearly complete. Younger individuals might have been at risk of possible damage to their growth plates during the plyometric push-ups. Once individuals reach an age in years around their mid 30's, a natural decline in muscular strength starts to occur.
- Participants had to have been currently been resistance training (minimum of 6 weeks training immediately prior to this study). This requirement allowed an appropriate amount of time for basic neuromuscular and physiological adaptations through resistance training to have occurred and potentially reduced the variability of their performance on the dependent variables associated with early learning in the performance of various exercises. In addition strength is a characteristic that is recommended to have before starting plyometrics.
- Participants had to be free from upper extremity injury. Requirements for participants included no acute, chronic muscle or joint problems in the shoulders, elbows, wrists, and back. This measure was taken to help reduce potential risk of injury from the performance of exercises.
- A written informed consent (Appendix B) was provided to participants who met the previously mentioned criteria and agreed to participate in this study. Participants signed a written informed consent after a demonstration of the exercises and they had an opportunity for questions and answers.

Recruitment

Upon approval from the University Committee on Research Investigating Human Subjects (UCRIHS) an announcement to recruit participants was sent out to kinesiology undergraduate and graduate students at Michigan State University (Appendix C). Flyers (Appendix D) were also posted at local gyms in order to secure individuals who met the study's requirements. Interested individuals who responded to the announcements were contacted. Through email or phone conversation an overview of the testing procedures was explained to each potential participant in regards to the purpose, participation requirements, and the possible implications of the study. If individuals wished to participate in this study, they were scheduled to arrive at the Biomechanics Research Station at Michigan State University on a Saturday for an orientation session. At the orientation, a demonstration of the exercises, to be performed by participants in the study, was given. After the demonstration, the informed consent and a questionnaire (Appendix E) were given to the participants who wanted to participate. Only participants who signed the UCRIHS informed consent forms were permitted to continue their involvement in the study. Participants were given an orientation session. No payment was provided to participants for their involvement. However, participants were promised their specific results and general group results for comparison.

Sample Size

The total number of participants in this study was 17 - 9 in Group 1 and 8 in Group 2. Significance was determined with a paired t-test at $p < .05$ level and conducted with a two sample t-test assuming equal variance. It was expected that differences between the two exercises were going to be large. Therefore, a larger number of participants were not required. Once the study was under way, if the results would have shown that the population size was not adequate for analysis, an effort would have been made to recruit more participants. In addition, repeated measures were taken during the test and retest sessions within 1 week. Since there were no significant differences in results between the two testing sessions, the data of both sessions were combined for each group to add power to the analysis.

Assignment of Participants to Groups

Assignments to groups were made after the orientation session (Table 1). Due to the strength requirements of the plyometric exercises, performing two different exercises, and possible fatigue; two groups were formed to help counterbalance the effect of multiple exercises and possible fatigue. Participant's names were randomly drawn to determine assignment to group. Then, before the test session, each participant was randomly assigned into Group 1 or 2 (e.g., MB or PU), during the test and retest sessions according to the exercise method they were performing first.

Exercise Conditions

Push-ups

Push-ups were performed in this study with the concentric only, countermovement, and plyometric methods. See Figures 1-3. Each of these methods consisted of the participant giving maximal effort during the concentric contraction.

The concentric only method (Figure 1) started from the position with the chest on the push-up platform, shoulders over the hands, and the elbows and shoulders flexed over the force platform (Figures 4). The hands were located at the same position in the countermovement method. The exercise began when a push-off was performed quickly by concentric contractions of the muscles of the upper body to elevate the body as high as possible and land with the hands on the push-up platform. This was the same objective for the countermovement and concentric only method. For the concentric only and countermovement method a push-up platform was used that was approximately 15 ½ cm high from the top surface of platform to the floor; Figure 5).

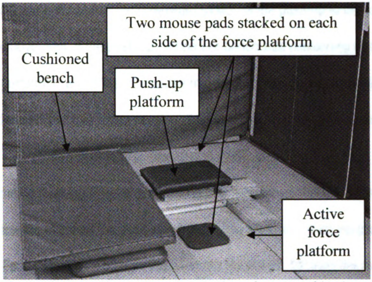


Figure 4. Push-up platform built to help protect participants during the performances of the plyometric push-ups

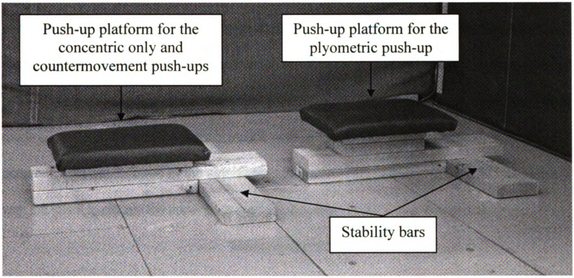


Figure 5. Two push-up platforms built for the push-up exercises

The countermovement push-up (i.e., standard push-up; Figure 2), involved starting with the upper extremities extended and hands on the force platforms on each side of the push-up platform. The hands were located approximately in the middle of the force platforms on the stacked pairs of mouse pads. When cued the participant would lower the body down from the starting position as quickly as possible until immediately before the chest touched the push-up platform. Once this position was reached the concentric phase of the push-up was performed forcefully to elevate the upper body as high as possible. The push-up platform served as a reference point for participants to know when to convert the downward motion of the push-up to the upward motion during the countermovement. If the push-up platform or bench with cushioning were touched by the participant in the performance of either the countermovement or plyometric push-up during the eccentric phase during the test or retest session, the trial was not counted and a retrial was performed.

The plyometric push-up (Figure 3) started with the upper extremities extended with the hands directly below the chest on the push-up platform (top surface of push-up platform around 20 cm high from the floor; Figure 5). To begin the exercise, the hands released the push-up platform and then fell onto the mouse pads located on each side of the push-up platform. One stacked pair of mouse pads was located on an active force platform and another stacked pair was located in a similar position on the inactive force platform on the opposite side of the push-up platform. When falling, the hands were positioned under the shoulders with the arms slightly bent. Once the hands made contact with the stacked pairs of mouse pads, eccentric contractions of the upper body occurred. This was followed by the amortization phase and then concentric contractions to push-off with the intent to elevate the upper body high as possible.

Medicine Ball Throw

Medicine ball throws were performed in this study with the same methods as the push-ups. See Figures 1-3. Like the push-up each of these methods for the medicine ball throw consisted of the participant giving maximal effort during the concentric contraction. The beginning position for all methods was with the participant lying on the force platform; shoulder blades in the center of the force platform, head off of the force platform, knees bent, and feet on the floor.

The concentric only method started with the arms horizontally abducted (i.e., around 90 degrees), the elbows flexed, and the medicine ball positioned in the participant's hands to where the ball was resting on the participant's chest. (Figure 1). Once signaled the ball was to be thrown as high as possible, same for the countermovement and plyometric methods. A spotter was on hand to catch the ball once it was propelled into the air for all methods of throwing the medicine ball.

The countermovement method (Figure 2) started out with the ball in both hands of the participant at arms length above the chest. The hands were slightly cupped, wrists hyper extended, and the palms facing up. On the count of three the ball was lowered down quickly by the upper extremity toward the chest. Right before the ball hit the chest a push-off was generated by the upper body to throw the ball straight up as high as possible. If the ball touched the chest during the countermovement or plyometric method a retrial was performed

The plyometric method (Figure 3) started with the ball positioned 1 m above the palms of the hands when the wrists were hyper extended and the elbows were fully extended. The drop height of 1 m is approximately the height recommended for this exercise by Baechle, Earle (2000), and Chu (1998). A 1 m drop height was shown previously in the Biomechanics Research Station to fall within a range that augmented the biomechanical parameters the most. Heights higher and lower than this decreased the ability to increase kinetic variables. A tester measured the distance from the participant's palm to the bottom of the ball being held by a tester. On the count of three the rope and attached ball were released by the tester from the 1 m height directly over the participant's chest. The participant started with the arms extended and slightly bent with the palms facing up prepared to catch the ball. Once the ball made contact with the participant's hands, the impulse of the medicine ball was countered by an eccentric contraction of the upper extremities. The upper extremities continue to push against the medicine ball, eventually changing its direction of motion (concentric phase of muscle contraction). The intent is to throw the ball as high as possible using this SSC pattern.

Instrumentation

Demographic Questionnaire

Participants took a demographic questionnaire prior to participation in the study. The questionnaire consisted of information about the participant's age, training and sports background. Refer to Appendix E.

Anthropometry

Anthropometric measures were taken of body length, width, and weight. Typically two to three measurements were taken for each of these anthropometric variables. Values of a particular variable were recorded when two measurements were similar (Appendix F). Equipment used for taking these measurements was the anthropometer (long and shortened), bow caliper, physician's weight scale, and force platform.

Length

The anthropometer was calibrated by measuring an object of a known length. The long anthropometer was used to measure standing height (Figure 6a) and the shortened anthropometer was used to measure upper extremity length (Figure 6b). After calibration, standing height and the upper extremity length (i.e., combined length of arm, forearm, and hand) were measured with the anthropometer. Both height and length were measured to the nearest centimeter. The anthropometer provides a direct measurement of length which has face validity.

height.

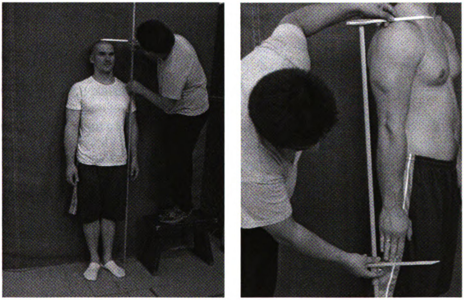
Participants did not wear shoes for the measurement of their height (Figure 6a). During the measurement of height, the participants stood against a wall with the posterior aspects of their heels against the wall and their head in the Frankfort position (i.e., head facing straight forward with eyes and ears forming a horizontal line). Measurements of height were taken from the floor to the highest peak of the head.

upper extremity length.

The upper extremity length was recorded with the shortened anthropometer (Figure 6b). Measurements were taken on the right side of the participants' acromion process to the tip of their middle finger with the upper extremity fully extended.

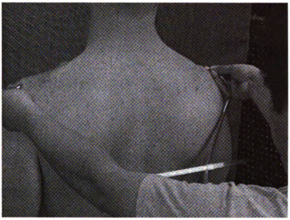
Width

Biacromial width is the distance between the outer edges of the right and left acromion process. A bow caliper was used to measure biacromial width (Figure 6c). The bow caliper was calibrated by first closing the calipers until the olive tips were touching. At this point, the measurement was checked for zero reading. Then a ruler was positioned between the olive tips of the calipers to determine if the readout on the bow caliper matched the known length. The bow caliper is a device that is used to directly measure width and has face validity.



(a) (b)

(Figure 6 continued)



(c)

Figure 6. Anthropometric measurements taken of standing height using long anthropometer (a), upper extremity length using short anthropometer (b), and biacromial width using bow caliper (c)

Weight

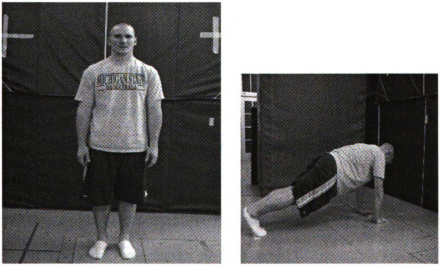
Each participant's weight was measured and compared through the use of a physician's scale and a force platform. The physician's scale and force platform were calibrated by taking all objects off the scale and platform and setting the output to zero. Then a known weight was put on the scale and the force platform to see if the weight displayed on each instrument matched the known weight. Participant's total and upper body weights were measured on the force platform. Both the physician's scale and force platform have face validity when used correctly.

total body weight.

Participant's total body weight was recorded to the nearest quarter pound (0.113 kg) while they stood on a physician's scale (Health O Meter's 402KLS physician balance beam scale). Participant's total body weight was recorded in kilograms while they stood on the force platform. The two measures of total body weight were compared (Figure 7a). Participants did not wear shoes for the measurement of their total body weight.

exercise position.

In addition, measurements of weight of each participant's upper body were taken using the force platform for the push-up and medicine ball throw. For the push-up participants positioned themselves in a front leaning push-up position with their hands directly under their shoulders in the middle of the active and inactive force platforms. Their legs were extended in a straight line out from their body. They held this position and weight was recorded (Figure 7b). Another weight measurement of the participants was taken for the medicine ball throw. For this measurement, the participant laid on his back with his legs extended out from the force platform. His head, abdomen, and lower extremities were off the force platform and his shoulder blades were centered and in contact with the force platform (Figure 7c).



(a) (b)

(Figure 7 continued)

(c)

Figure 7. Weight experienced by the force platform measured for the total body (a), front leaning position in the push-up (b), and back lying weight for the medicine ball exercises (c)

Peak Force

The AMTI force platform (Figure 8) used in this study was a strain gauge type device that provided analog data to the Ariel Performance Analysis System (APAS) software where vertical force data were sampled, converted to digital values, and stored on a computer. Ground reaction forces from the exercise movements were measured by the force platform in kilograms, which has face validity. The sampling frequency selected for this study was 1000 Hz for recording force associated with the subjects' exercises and 100 Hz for recording the weight of the subjects. One force platform was used in data collection for the push-up and medicine ball throw exercises. Vertical force values enabled calculations to be made of peak force, MRFD, and average power output. Only force values were displayed on the computer, the other two variables were later calculated later. These three variables were analyzed in the push-off phase of both exercises. Calibrations of the force platforms were previously described for weighing the participants.

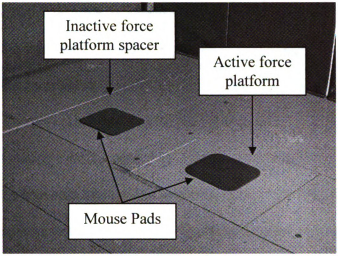


Figure 8. Force platform on the right used to record data in this study

For the force output calculations for the push-up exercises, each participant's push-up front leaning position weight was measured directly from the force platform. To calculate force, in Newtons, the amount of weight, in kilograms, applied to the platform during the trial was multiplied by the acceleration due to gravity (Figures 9-11).

Force (N) = ((absolute (recorded weight from force platform (kg))*9.81 m/s^2)*2)

Absolute refers to the making a positive value from a given negative value.

However, for each participant in the medicine ball throw, the vertical force recorded via the force platform and APAS system was equal to the weight of the participant on the force platform in the back lying position plus the forces associated with the acceleration of the mass of the medicine ball when in contact with the participant's hands and the acceleration of the mass of the upper body segments. To determine the force applied by the upper body in the medicine ball throw, the weight of the individual on the platform was subtracted from the force reading (Baca, 1999; Young, Wilson, & Byrne, 1999i).

Force (N) = (absolute ((weight of participant in the back lying position plus ball (kg)) *9.81 m/s^2) – (recorded weight of participant in the back lying position (kg))*9.81 m/s^2)

Absolute refers to the making a positive value from a given negative value.

A separate calculation had to be made for the plyometric medicine ball throw since the ball did not start out as a part of the initial weight on the force platform.

$$\text{Force (N)} = (\text{absolute (recorded weight (kg))}*9.81\ m/s^2) - (\text{recorded weight of participant in the back lying position (kg)})*9.81\ m/s^2)$$

Absolute refers to the making a positive value from a given negative value.

The highest force value from each exercise trial was taken as peak force and used for data analysis. There was no manufacturer's information reported in regards to the reliability of the force platform measuring dynamic forces.

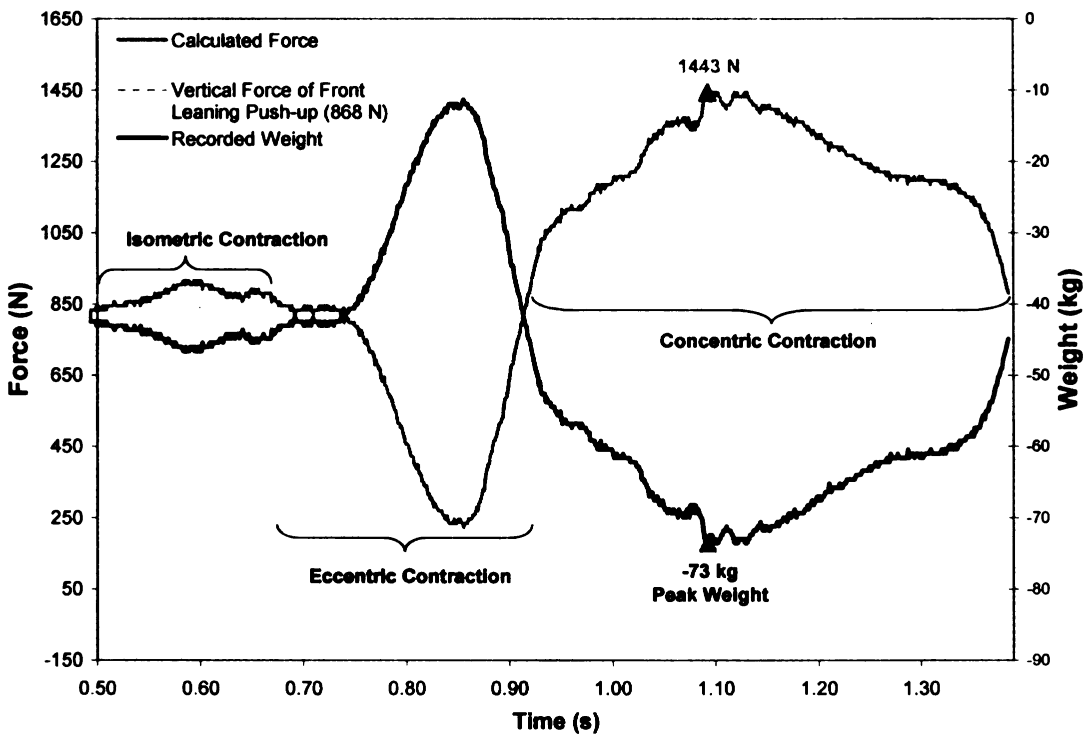


Figure 9. Typical force patterns of the countermovement push-up for participant 05MB (front leaning push-up position = 44 kg). The same process of calculation was also used on the concentric only and plyometric methods for the push-up.

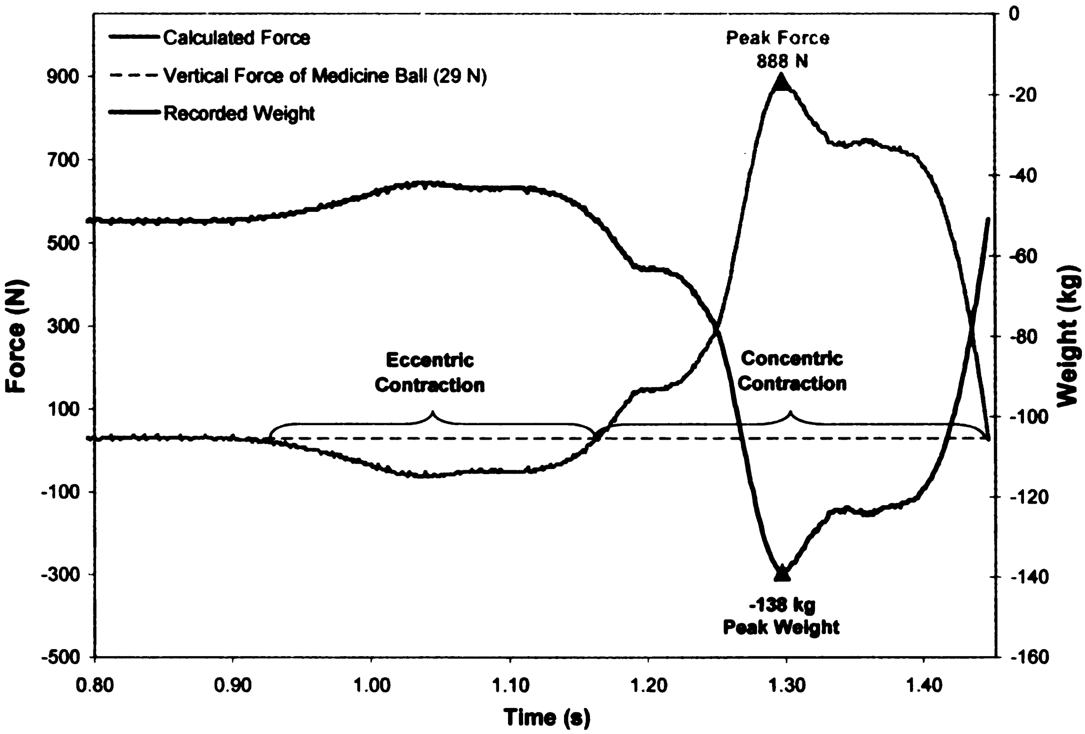


Figure 10. Typical force patterns of the countermovement medicine ball throw for participant 05MB (back lying weight = 51 kg). The same process of calculation was also used for the concentric only medicine ball throw.

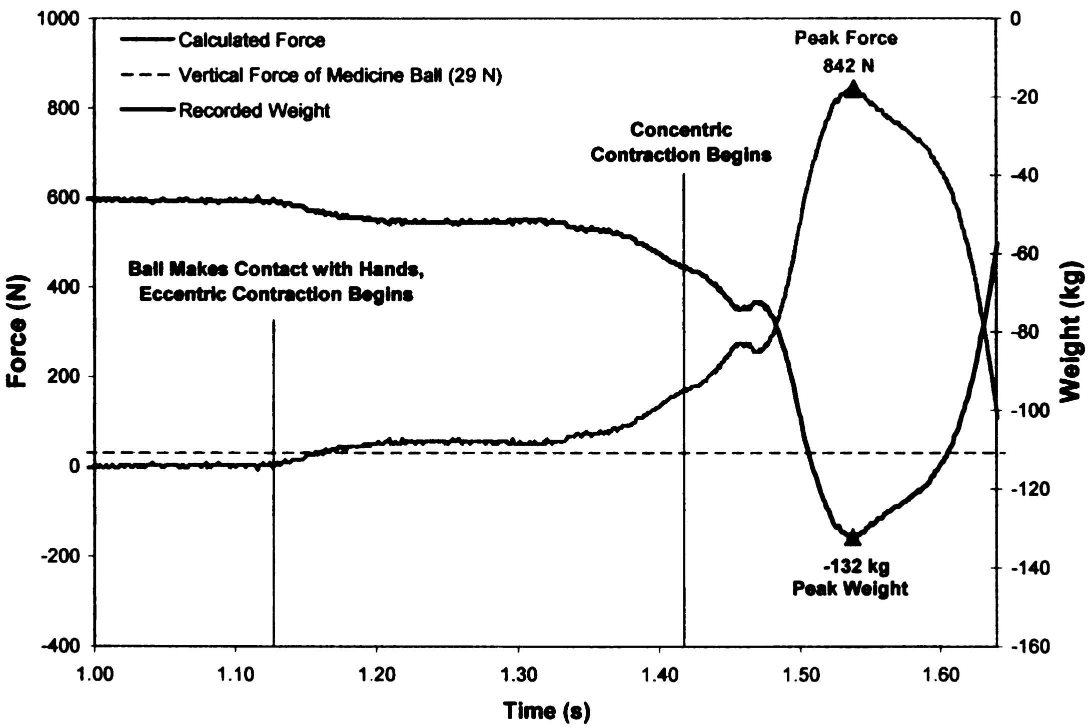


Figure 11. Typical force patterns of the plyometric medicine ball throw for participant 05MB (back lying weight = 46 kg).

Maximal Rate of Force Development

To determine the MRFD (i.e., N/s), calculations of force output and time were required from the force platform. Since the sampling of the force platform was set at a 1000 Hz, small windows of time were taken to examine the change in force. These windows were divided up into 5 ms intervals. Two points of force (i.e., N) were examined in that window of time (T1 to T5) -the first point of force (i.e., F1) and the fifth point of force (i.e., F5).

$$RFD\ (N/s) = (F5-F1)/(T5-T1)$$

This process was continued using the corresponding force values for T2 and T6 to calculate the next value of RFD. From all calculated values of RFD, a MRFD was determined. This represented the force curve where the slope was the greatest. This approach has been used by others (Young & Behm, 2003). Since there are changes in force over very short periods of time (Figures 12-14), taking small intervals of time (i.e., 5 ms) allowed an accurate reading of the RFD and subsequent determination of MRFD compared to an overall reading when force output is initiated and when it peaks. However, when examining the RFD graph there are sudden changes in magnitude. These sudden changes in magnitude are due to large changes in force being magnified when the force interval is divided by time (i.e., first derivative) causing error components to magnify. Although not published, Young and Behm (2003) reported the intra-class correlation using these methods as .92 on separate days of testing.

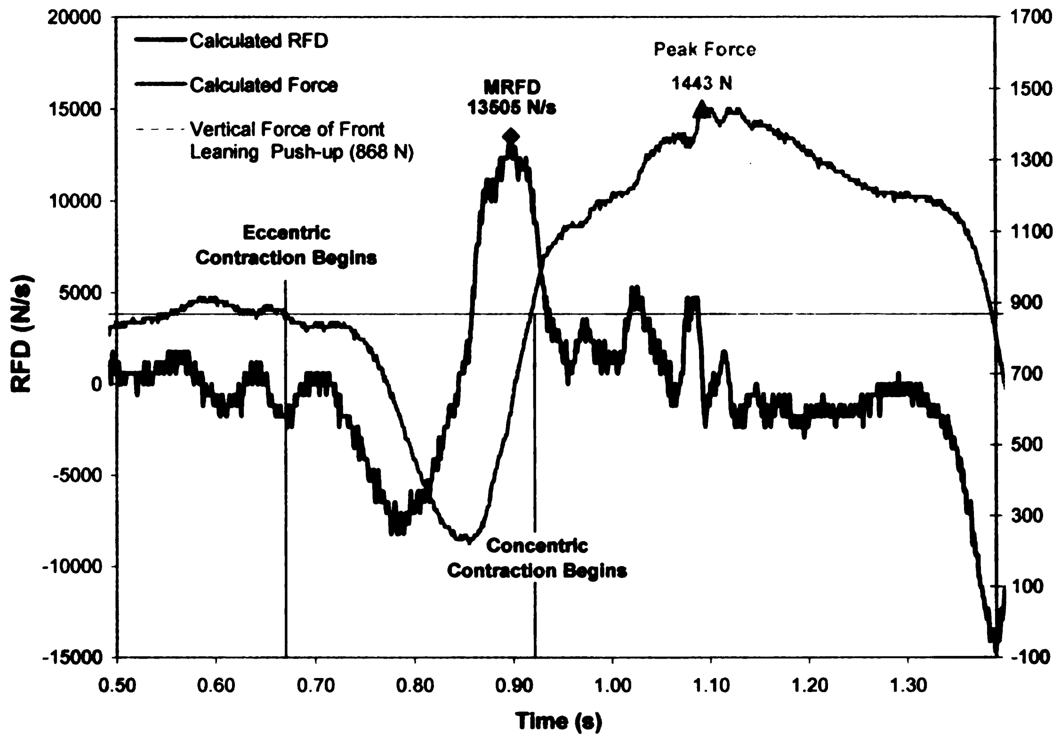


Figure 12. Typical RFD and force patterns of the countermovement push-up for participant 05MB (front leaning push-up position = 44 kg). The same process of calculation was used for all methods of exercise during the push-up and medicine ball throw. For this graph a larger window of time was used (20 ms) to calculate the RFD and smooth the data line. MRFD indicates the maximal rate of force development.

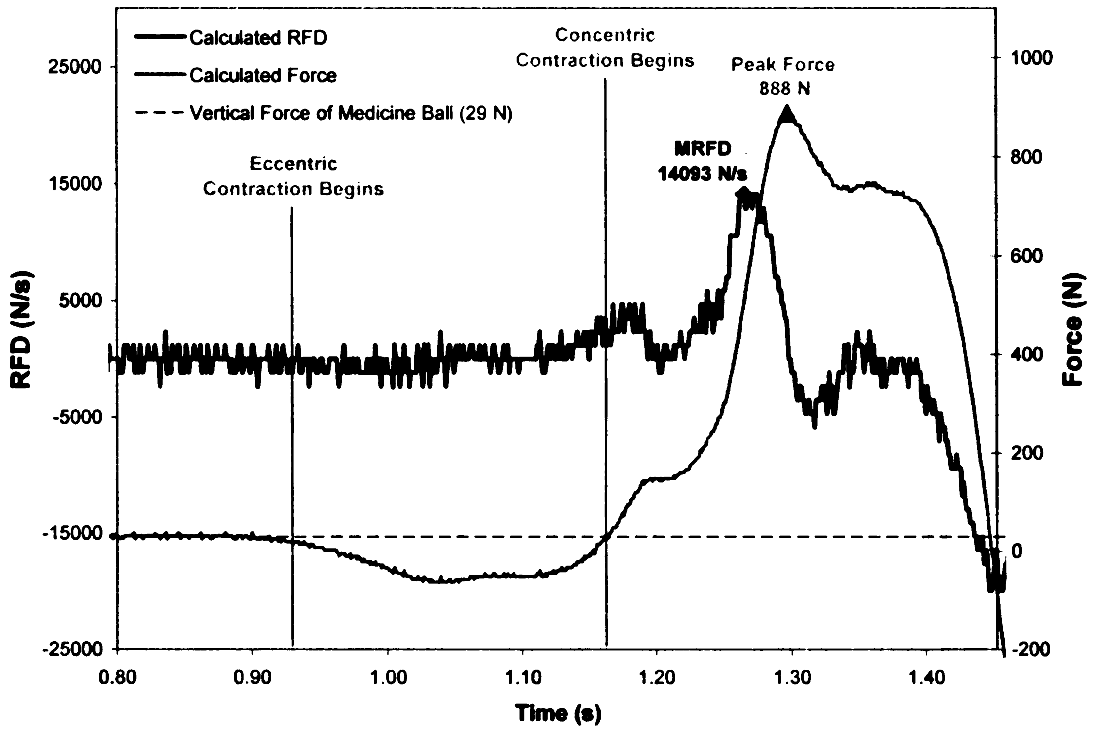


Figure 13. Typical RFD and force patterns of the countermovement medicine ball throw for participant 05MB (back lying weight = 51 kg). The same process of calculation was used for all methods of exercise during the push-up and medicine ball throw. MRFD indicates the maximal rate of force development.

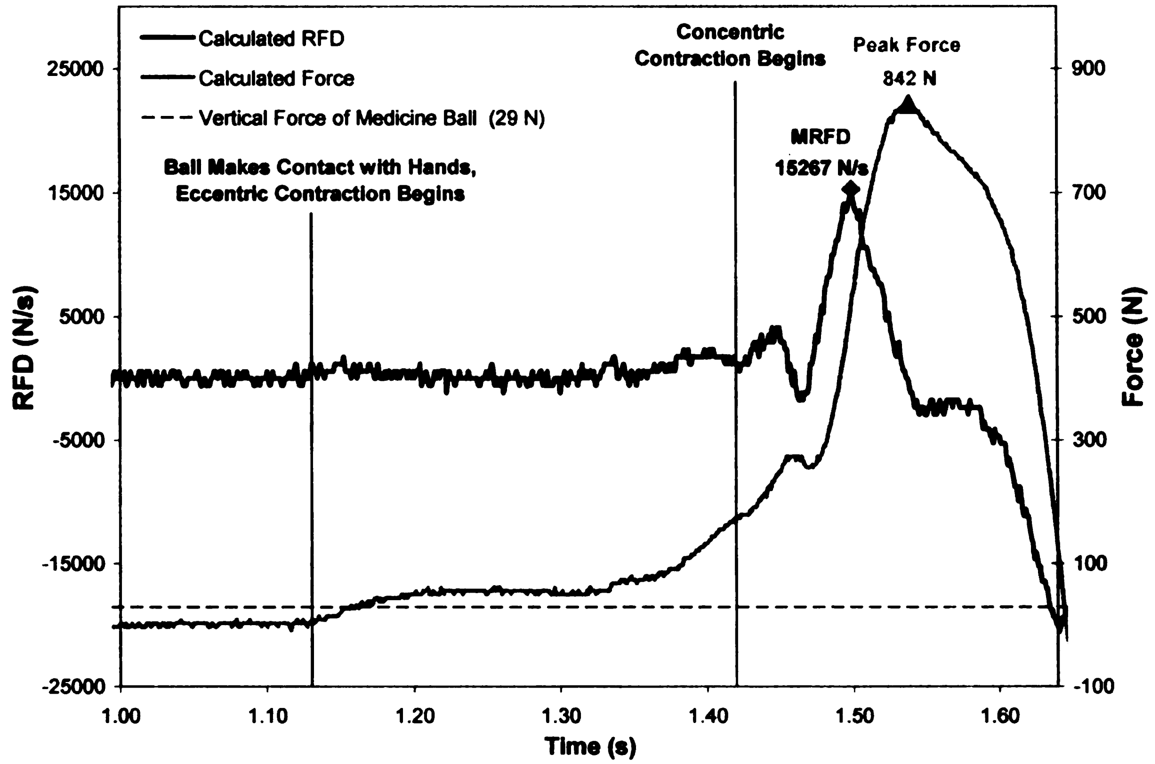


Figure 14. Typical RFD and force patterns of the plyometric medicine ball throw for participant 05MB (back lying weight = 46 kg). The same process of calculation was used for all methods of exercise during the push-up and medicine ball throw. For this graph a larger window of time was used (20 ms) to calculate the RFD and smooth the data line. MRFD indicates the maximal rate of force development.

Average Peak Power Output

A force platform and accelerometer (Figure 15) were used to determine the average peak power output (W). A uniaxial accelerometer (Microtron) was calibrated by setting the long side of the accelerometer parallel and perpendicular on a horizontal surface parallel to the floor. Calibration occurred for the accelerometer in a stationary position. The computer graph displayed the accelerometer experiencing 9.81 m/s^2, which is equivalent to the force of gravity.

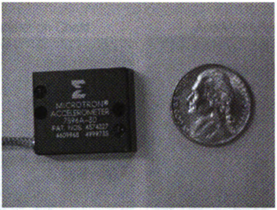


Figure 15. Accelerometer used to help determine the average peak power output

The recorded time histories of acceleration were synchronized with time histories of the force-time curves. The accelerometer was strapped to the sternum (Figure 16) for the push-up exercises and mounted to a plastic device which was inserted into a hole on top of the medicine ball (Figure 17) for the medicine ball exercises. The sampling frequency of the accelerometer was 1000 Hz. These set ups of the accelerometer allowed the values of acceleration of the chest and the medicine ball to be determined in the vertical direction. Since the accelerometer was attached to different surfaces (i.e., skin over the sternum and a plastic mount over the medicine ball), the acceleration values were expected to differ from a more accurate acceleration reading. Force readings (i.e., N) were recorded in conjunction with the acceleration readings (i.e., m/s^2) to determine the average peak power output during the push-off phase for each exercise method (Figures 18-20).

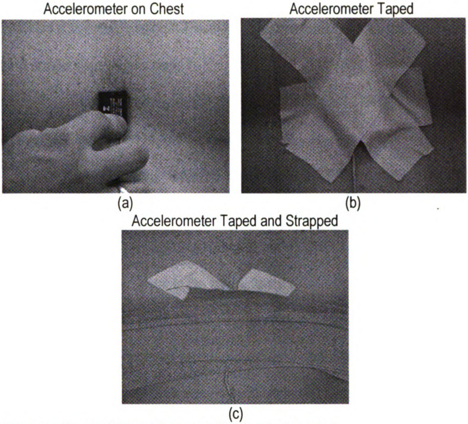


Figure 16. Process used to attach the accelerometer to the chest for the push-up

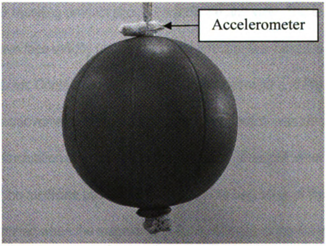


Figure 17. Medicine ball and accelerometer configuration for the medicine ball throws

For the push-up and medicine ball throw exercises all three methods used the same formula.

Power (W) = (force*distance)/time = (force)*(distance/time) = (force)*(velocity)

Velocity wasn't able to be directly measured since participants were unable to entirely fit their whole body on the active force platform. Therefore, an accelerometer was used since velocity is the product of acceleration (A) and time (T).

$$\text{Average velocity (m/s)} = ((A5+A1)/2)*(9.81\text{m/s}^2)*(T5-T1)$$

This value of velocity was multiplied by the average force.

$$\text{Average force (N)} = \text{absolute } ((F5+F1)/2)$$

Absolute refers to the making a positive value from a given negative value.

$$\text{Average power output (W)} = ((A5+A1)/2)*(9.81\text{m/s}^2)*(T5-T1)* (\text{absolute } ((F5+F1)/2))$$

This provided a window of time similar to the calculation of MRFD. Similar to the MRFD calculations, the next window evaluated average power output 1 ms later. The highest average peak power output from these windows was used for data analysis. No information found in the literature review incorporated accelerometers in conjunction with force platforms to determine the average power output. If each of these parameters is accurately measured and their time histories are synchronized, their resulting product should be accurate and valid. The force platform and the accelerometer both have face validity for measuring their respective variables.

Identification of Concentric Contraction during the Countermovement and Plyometric Methods

For the countermovement method, the eccentric contraction was identified from the force readings by the initial fluctuation of force due to the unloading of weight when lowering the body during the push-up or the medicine ball during the throw. The beginning of the concentric contraction was determined when the magnitude of force returned to the magnitude of force immediately prior to the participant beginning the exercise while on the force platform (Figures 9&10). In addition, the accelerometer was able to provide information on when the eccentric contraction ended and the concentric contraction began for the plyometric methods. When the value of acceleration reached zero during the exercise trial, it identified when the motion of the chest and ball for an instant was stopped on the way down before being pushed up. Therefore the beginning of the concentric contraction was determined when the acceleration value was zero for the plyometric methods.

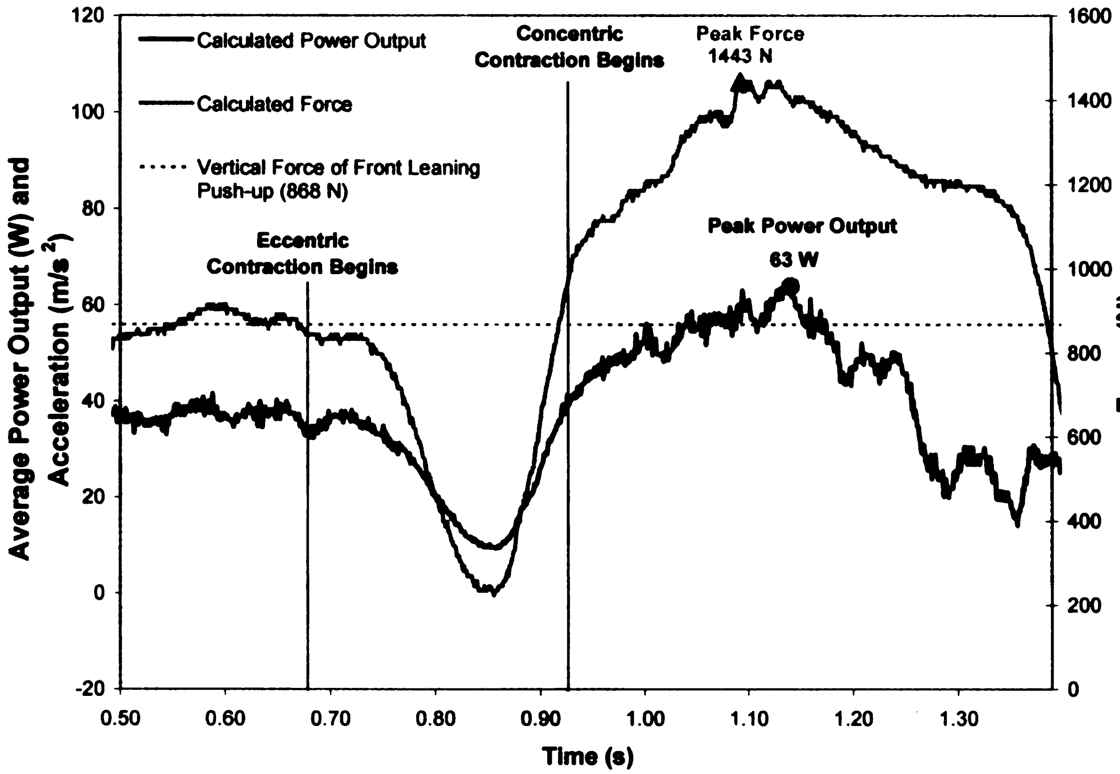


Figure 18. Typical average power output and force patterns of the countermovement push-up for participant 05MB (front leaning push-up position = 44 kg). The same process of calculation was used for all methods of exercise during the push-up and medicine ball throw.

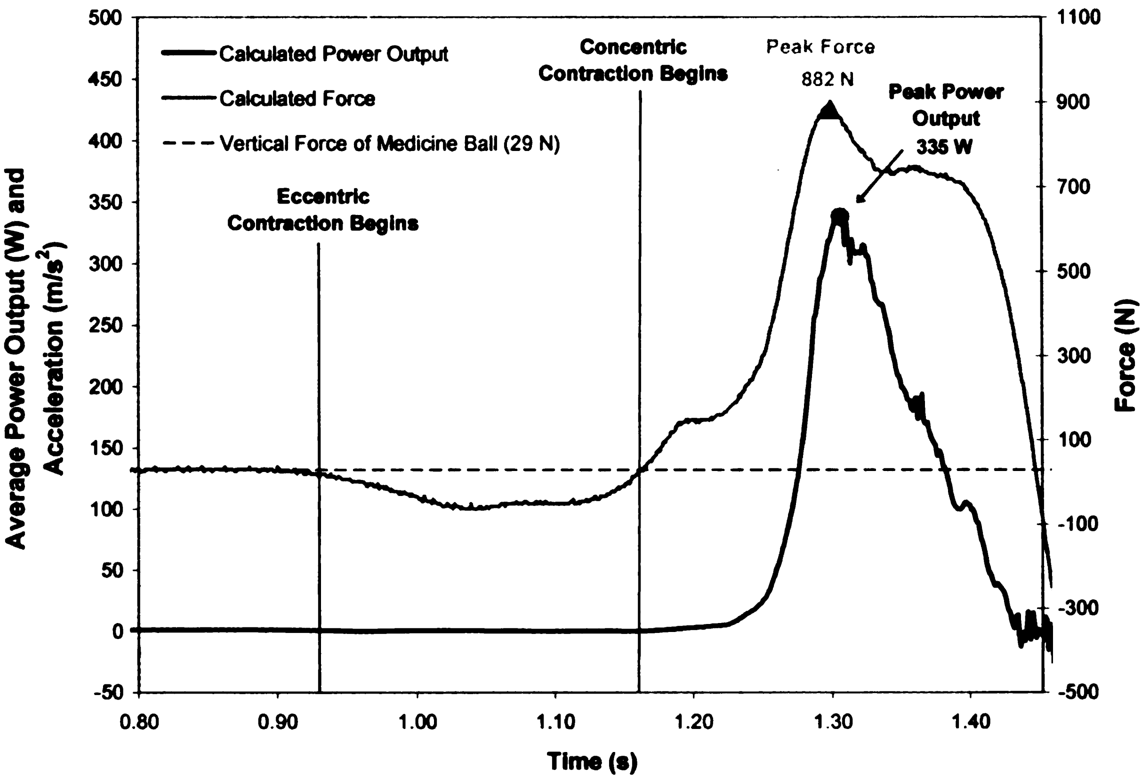


Figure 19. Typical average power output and force patterns of the countermovement medicine ball throw for participant 05MB (back lying weight = 51 kg). The same process of calculation was used for all methods of exercise during the push-up and medicine ball throw.

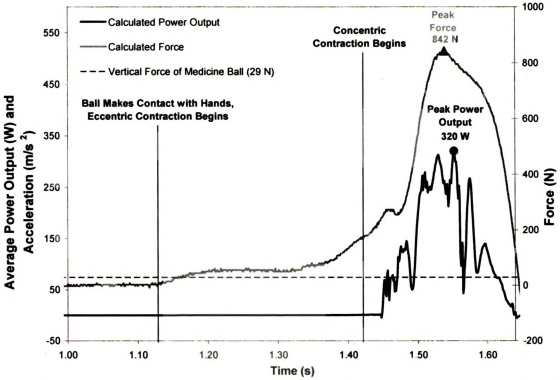


Figure 20. Typical average power output and force patterns of the plyometric medicine ball throw for participant 05MB (back lying weight = 46 kg). The same process of calculation was used for all methods of exercise during the push-up and medicine ball throw.

Additional Equipment Used in this Study

Push-up Platform.

Push-up platforms (Figure 5) were built for the participants to initiate their plyometric push-ups. Using a set of platforms insured that all participants started from the same drop height, allowed them more hand room, and provided excellent stability. The highest push-up platform used for the plyometric push-up was well cushioned. Because of the cushion, its height was determined to be approximately 20 cm tall and the second platform was similarly built and used for the concentric only and countermovement push-ups. Its height was approximately 15 ½ cm.

Medicine Ball and Support.

A 3 kg medicine ball was used for the throws (Figure 17). The weight of the ball was selected due to typical recommendations provided by experts (Baechle & Earle, 2000; Chu, 1998).

This ball was purchased from Power Systems, Inc. (2527 Westcott Blvd. Knoxville, TN 3793). The open ball used for the throw is rubberized on the outside. The ball is spherical with a narrow column passing through its center and forming a diameter. A rope passed through the column of the medicine ball. It was attached to a wooden beam directly above the center of the force platform by the rope. The wooden beam was secure. As a safety precaution, the length of the rope was adjusted for each participant so that, when the ball fell, it would stop short of making contact with the participant's chest (Figure 21).

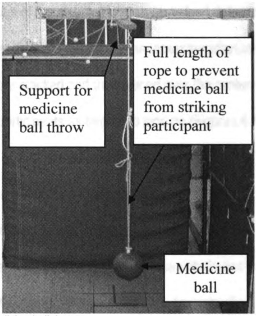


Figure 21. Setup used for the medicine ball throws

Meter Stick

For the plyometric medicine ball throw, the participant assumed a supine back lying position with the upper extremities extended in a vertical alignment. The wrists were hyper extended in preparation to receive the medicine ball. A meter stick was used to insure a 1 m distance from the inferior point on the medicine ball to the palms of the cupped hands.

Mouse Pads

For plyometric push-ups absorbing surfaces are recommended to help significantly decrease landing impact forces and to aid in the prevention of injury (Hewett, et al., 1996; McNitt-Gray, 2001). The use of elastic surfaces has been proven to help reduce the contact time and augment the forces used to project the body (Krug, Minow, & Jassmann, 2001). However, using surfaces too thick (15 cm) will attenuate force generation (Baechle & Earle, 2000). Other recommendations include mats of 7.62–10.16 cm in thickness placed shoulder width apart (Chu, 1998). Preliminary evaluations of the plyometric push-up helped determine that two stacked mouse pads per hand was a safe landing surface without unnecessary attenuation of ground reaction forces. Two mouse pads were stacked and then placed over the center of each force platform (i.e., active and inactive) for the participants as targets to land on (Figures 4 & 8).

Data Collection Procedures

There were three data collection sessions, the orientation, test, and retest session. Each session was an individual session separated by at least 24 hours. Data was collected at the Biomechanics Research Station. The Biomechanics Research Station consists of two primary components: the deck and the computer room. The deck consists of a raised platform with two embedded force platforms whose locations are adjustable. The deck is approximately 15.5 by 4 meters with an additional film/video access at the level of the deck and from overhead. The computer room is a 4 by 3 meter space with additional storage room that houses computer software and hardware, amplifiers, and video and cine cameras.

Orientation Session

Prior to each orientation session the force platform and anthropometric devices were calibrated as previously described under *Anthropometry* the accelerometer was calibrated as previously described under *Average Peak Power Output* by the author and doctoral or graduate student. Individuals interested in participating arrived at the Biomechanics Research Station for an orientation session and were required to dress in comfortable athletic shorts or pants, and athletic shoes for all sessions. Once the individual arrived he was given a demonstration of the exercises that were to be performed during the testing sessions by the author. Refer to Table 2 for a summary of the orientation, test, and retest sessions.

In the orientation session a demonstration of push-up and medicine ball throw exercises to be performed, as previously described under Exercise Conditions, by the participants in the test and retest sessions was given by the author. Individuals who wished to participate read and signed a consent form (Appendix B). In addition, a questionnaire was given (Appendix E), following the signing of consent forms, to gain information about the participants' resistance training and sports background. Following the consent and questionnaire anthropometric measurements (Appendix F) were taken.

Anthropometric measurements of the participant's upper extremity length, biacromial width, height, and weight were recorded and kept on a form (Appendix F) and taken by the author, graduate and doctoral students as previously described under *Anthropometry*. Participants were first weighed on a physician's balance beam scale. Then they were weighed on the force platform in three different body configurations: standing, in a push-up position with their hands on the force platform (front leaning position) and lying on their back with their shoulder blades on the force platform and their heads slightly off the force platform (Figure 7). When they were weighed in the front leaning push-up position, a piece of tape was placed where there shoes were in contact with the floor. A measurement was then taken from the closest edge of the force platform to tape and was kept as a record for future data collection sessions to assist in configuring the subjects in approximately the same position. Standing height was measured with the long anthropometer from the floor to the apex of the head (Figure 6 a). Next, a measurement was taken with a short anthropometer of the upper extremity length (Figure 6 b). Measurements were taken with a bow caliper of the biacromial width (Figure 6 c). Following anthropometric measurements, the upper body strength was tested.

The strength testing protocol used was derived from NSCA's guidelines for a 10 repetition maximum load (Baechle & Earle, 2000). The strength tests were conducted by the author, graduate, and doctoral students. Participants started with a non-challenging weight, a weight they selected that they normally used before lifting heavier loads that they could easily perform 10 times. The second set was more difficult because a judgment was made about adding 10-20 pounds (4.54-9.08 kg), yet permitting the participant to complete 10 repetitions. After the first and second sets, a 1 min rest was given. The same process was followed in the third, fourth, and fifth sets where typically 5-10 pounds (2.27-4.54 kg) were added. The test was terminated and the weight and repetitions recorded when the participants were to the point of total fatigue on the tenth repetition or during the set when participants were unable to achieve 10 repetitions. Two minutes of rest were given between the third and fourth sets if those sets were necessary. Spotters were used to insure safety during all bench press sets. With the use of a table from the NSCA (Baechle & Earle, 2000) maximum upper body strength was estimated based on the weight and the number of repetitions participants were able to achieve on their final set. After recording and determining each participant's maximal strength, each subject was then familiarized to each exercise.

Participants practiced each method for the push-up and medicine ball throw used in the study as described under Exercise Conditions. For each exercise participants were coached by the author and practiced until they demonstrated an ability to perform the exercise correctly and felt comfortable. Usually each exercise method involved no more than three practices. During the practices, a verbal count to three was given to the participant to let them know when to begin the exercise. This count was used to accustom them to the testing sessions that followed. The push-up exercises involved a push-up platform and a cushioned bench beneath the body for safety purposes (Figure 4). A pad, built onto the push-up platform, was positioned between the right and left shoulders. A bench with cushioning was placed beneath, and perpendicular to the length of the body, under the trunk. All three methods of the medicine ball throw involved the participants lying down on their back, centering their shoulder blades on the active force platform and positioning their heads off of the force platform (Figure 7 c). An accelerometer was attached to a mount fixed on top of the medicine ball. A mounting device was used to protect the accelerometer from being hit and to provide a stable area to attach the accelerometer (Figure 17). The recommended medicine ball weight used for this exercise ranges from 0.907-3.629 kg (Baechle & Earle, 2000) and data from our lab showed that a 2.722 kg produced optimal biomechanical variables when compared to lighter balls. A 3 kg was chosen for the previously mentioned reasons. The medicine ball was attached by a rope to a fixed beam directly above the force platform (Figure 21). The full length of the rope was adjusted to prevent the ball from hitting the chest during the plyometric method.

The orientation sessions ended with the author directing standing static stretches directed (30 s for each stretch) for the chest, shoulders and triceps. The first stretch involved grabbing a towel with both hands wider than shoulder width. Keeping the hands in the same position on the towel the arms were pulled upwards over the head and then back behind the head and held. The other stretch involved taking the right arm straight up over the head bending the elbow to where the forearm and hand hung down behind the back. Then with the left hand the right elbow was grabbed and pulled towards the floor (the opposite for stretching the left side). Static stretching as part of the warm-up performed before exercise trials has been reported to reduce the ability to generate maximum force (Young and Behm, 2003).When the stretching exercises were completed, future dates were scheduled for testing the participants. Once the orientation sessions were over for that day, participants were randomly assigned into either Group 1 or Group 2.

Table 2. Overview of Orientation, Test, and Retest Sessions for Group 1 and Group 2

Orientation Session
Orientation, initial measurements, and group formation
1. Orient subjects to study 2. Signing of consent form and survey 3. Take selected measurements 4. Test subjects upper body strength 5. Familiarize subjects to exercise methods 6. Stretch 7. Assign participants into groups

Test Session	
Group 1	1. Warm-up with push-ups
	2. Perform medicine ball trials (x 3)
	3. Perform push-up trials (x 2)
	4. Stretch
Group 2	1. Warm-up with push-ups
	2. Perform push-up trials (x 3)
	3. Perform medicine ball trials (x2)
	4. Stretch

Retest Session	
Group	1. Warm-up with push-ups
Group 1	2. Perform medicine ball trials (x 2)
	3. Perform push-up trials (x 3)
	4. Stretch
Group 2	1. Warm-up with push-ups
	2. Perform push-up trials (x 2)
	3. Perform medicine ball trials (x3)
	4. Stretch

Test and Retest Sessions

Before the test or retest sessions the force platform and accelerometer were calibrated and synchronized by the author, graduate and doctoral students. During the test and retest sessions, each participant was tested separately at the Biomechanics Research Station, around the same time of the day. A 48 hour rest period between the orientation and testing sessions was given. Participant's dressed in athletic shorts and shoes. The warm-up sessions for these two testing sessions involved participants performing two sets of 10 standard push-ups without an explosive concentric component. Refer to Table 2 for a summary of this section.

Prior to testing participants in the push-up exercise, the accelerometer was attached to their skin exterior to the sternum (Figure 16) by the author. Before the medicine ball trials, an accelerometer was attached to a hard plastic cylinder firmly inserted into the hole that ran through the center of the medicine ball (Figure 17) by the author. Depending on which group a participant was in, they began with either the push-up or medicine ball trials. The exact same methods described under Exercise Conditions and practiced by the participants in the orientation session for the push-up and medicine ball throw were performed. The concentric only method was tested first, and then the countermovement, followed by the plyometric method for the push-up and medicine ball throw in both groups. Group 1 started with the medicine ball exercise methods and then the push-up exercise methods. For the participants in Group 1, three trials were performed for each medicine ball throw method and two trials for each push-up method for the first testing session. During the retest of the participants in Group 1, only two trials were performed for each medicine ball throw method and three trials were performed for each push-up method. For the first test Group 2 performed the push-up exercises first, completing three trials for each method, followed by two trials for each medicine ball throw method. For the retest, Group 2 started with two trials for each push-up method followed by three trials for each medicine ball throw method. Each exercise trial was initiated by a tester, either a graduate or doctoral student, counting to three, which signaled the participant to begin the exercise. On two, a tester started recording the synchronized force and acceleration data for 4 s. Two minutes of rest was given by the author to the participant between each exercise (i.e., push-up and medicine ball throw) and 30 s of rest occurred between each trial within each exercise. The author kept time of the rests with a watch to insure rest time was sufficient and not exceeded. At the end of each session, individuals performed the same static stretches for the chest, shoulder, and triceps as they had performed for the orientation session.

Data Collection Personnel and Qualifications

This author's responsibilities included setting up and calibrating equipment before orientation and testing sessions occurred. All exercise methods performed by the participants were administered and spotted by the author. This could be accomplished since the trigger to initiate the recording devices had the ability to be positioned where testing was performed. In addition, a time lapse occurred between the initiation of recording and the exercise trial. The primary investigator, who is a departmental advisor for sports biomechanics, oversaw orientation, testing, and retesting sessions on a periodic basis to insure proper testing procedures and provide insight. Assistants who participated in the testing of this study were graduate and doctoral students in sports biomechanics who had experience with the equipment and/or exercises. These students were involved with triggering the recording equipment, observing the force patterns displayed on the computer screen, and providing feedback on the participant's performance.

Data Management

Participants were coded according to a numbering and lettering system for privacy and identification of participant, group, exercise method, exercise performed, and trial. A number was used to code for the participant based on the chronological order of their participation (e.g., 01 for first). Another set of letters was designated; CO for the concentric only, CM for the countermovement, and PLY for the plyometric method. Then, based on which trial it was (five total) a letter was assigned (i.e., A-E) according to the number of trials they performed. For example if the first person was in the push-up group and performing the countermovement push-up for his third trial the code would be 01PUCMPUC. All recorded information was stored on a computer that was housed in the locked biomechanics office accessible only to selected graduate students and the primary investigator. Information gathered from this study will be destroyed 5 years post publication.

Data Analysis

Participant Characteristics

Information about the participants' age, weight, height, shoulder width, upper extremity length, strength, and exercise performance were recorded. From this information, means and standard deviations (Table 3) of the population were made.

Tests of Hypotheses

A three-step analysis was conducted to compare the groups' performances in determining statistical significance of the hypothesized results. The purpose of these calculations were to determine if the test and retest sessions could be analyzed together for the final statistics. Group differences were not a focus of this study. Groups were formed only to increase internal validity of this study. Statistics were conducted on a combined sample.

The first assessment was a non-parametric procedure that involved ranking the third trial to the first and second to determine if there were major differences in the participants' trials. This analysis determined the effects of the groups performing a different number of repetitions during the sessions. Following analysis of the participants' performances, a trim mean (i.e., elimination of the highest and lowest scores and an average of the remaining scores) was conducted on biomechanical parameters. Using the trim means helped to eliminate extreme scores that were recorded and was used for the following analysis. The second assessment involved analyzing session-to-session differences for both groups using a paired t-test (p<. 01). Following that analysis, a calculation with a paired t-test was conducted to determine if significant differences existed between the two exercises measured parameters at p<. 05. The final data analysis tested the previously stated assumptions made in this study. A paired t-test was used to check if there were major differences between the type of methods (concentric only and countermovement, countermovement and plyometric, concentric only and plyometric) within each exercise (push-up or medicine ball) at p<. 05.

- Hypothesis 1 – Concentric method, push-up versus medicine ball throw
    - Push-up > medicine ball throw for peak force.
    - Push-up < medicine ball throw for MRFD.
    - Push-up < medicine ball throw for average peak power output.
- Hypothesis 2 – Countermovement method, push-up versus medicine ball throw
    - Push-up > medicine ball throw for peak force.
    - Push-up < medicine ball throw for MRFD.
    - Push-up < medicine ball throw for average peak power output.
- Hypothesis 3 – Plyometric method, push-up versus medicine ball throw
    - Push-up = medicine ball throw for peak force.
    - Push-up = medicine ball throw for MRFD.
    - Push-up = medicine ball throw for average peak power output.

Tests of Assumptions

- Peak force in concentric only < countermovement < plyometric method for both the push-up and medicine ball throws.

- MRFD in concentric only < countermovement < plyometric method for both the push-up and medicine ball throws.
- Average peak power output in concentric only < countermovement < plyometric method for both the push-up and medicine ball throws.

CHAPTER 4
RESULTS

The results of this study will be discussed in the following paragraphs. These results provide a statistical analysis of the participants, hypotheses, and assumptions.

Participants

There were 17 participants in the study whose anthropometric measurements and strength were recorded and analyzed. Comparisons between the groups showed no significant differences in the height, weight, biacromial width, upper extremity length, absolute strength, and relative strength (Table 3). Nine participants were in Group 1. This was the group that performed the medicine ball exercises first during the testing sessions. In Group 2 there were 8 participants and they performed the push-up exercises first.

Table 3. Anthropometric and Strength Measurements

	Sample
Participants (n)	17
Age (yrs)	24.00 ± 3.02
Height (cm)	179.14 ± 6.01
Weight (kg)	76.99 ± 12.28
Biacromial Width (cm)	41.68 ± 2.00
Arm Length (cm)	75.93 ± 3.59
Absolute Strength (kg)	104.24 ± 23.83
Relative Strength	1.35 ± .22

Descriptive Data for Test of Hypotheses

Table 4. Differences in Peak Force, MRFD, and Average Peak Power Output for Push-up and Medicine Ball Exercises Performed as Concentric Only (CO), Countermovement (CM), and Plyometric (PLY) Methods

	Push-ups M ± SD	Medicine ball throw M ± SD	$t_{(15)}$	p
Peak Force (N)				
Entire Sample (n=17) CO	1003.25 ± 217.04	371.04 ± 171.73	17.54	.00*
Entire Sample (n=17) CM	1224.63 ± 196.11	455.15 ± 158.77	20.50	.00*
Entire Sample (n=17) PLY	1254.90 ± 235.11	602.98 ± 167.51	13.98	.00*
MRFD (N/s)				
Entire Sample (n=17) CO	11244.47 ± 3028.08+	6965.83 ± 3023.98	4.86	.00*
Group 1 (n=9) CO	9690.85 ± 2053.99	7002.96 ± 3515.05	2.47	.02*
Group 2 (n=8) CO	12992.30 ± 3089.02	6924.06 ± 2603.29	5.16	.00*
Entire Sample (n=17) CM	12468.08 ± 2183.38	6954.83 ± 2058.78	9.56	.00*
Entire Sample (n=17) PLY	20739.92 ± 7506.88+	12600.72 ± 4349.10	3.85	.00*
Group 1 (n=9) PLY	16518.26 ± 5797.22	13307.81 ± 5568.56	1.33	.11
Group 2 (n=8) PLY	25489.29 ± 6457.97	11805.23 ± 2535.51	5.63	.00*
Average Peak Power Output (W)				
Entire Sample (n=17) CO	106.75 ± 31.72+	90.68 ± 59.01	1.09	.29
Group 1 (n=9) CO	91.55 ± 32.94	86.26 ± 68.97	.19	.43
Group 2 (n=8) CO	123.85 ± 20.72	95.66 ± 49.68	2.18	.03*
Entire Sample (n=17) CM (W)	125.19 ± 51.76	132.73 ± 66.77	.33	.74
Entire Sample (n=17) PLY	167.58 ± 59.86+	209.93 ± 101.85	1.55	.14
Group 1 (n=9) PLY	133.71 ± 36.76	242.26 ± 124.61	3.17	.01*
Group 2 (n=8) PLY	205.69 ± 59.25	173.56 ± 55.79	1.31	.12

*Significant difference in the biomechanical parameters between the push-up and medicine ball throw at the .05 level.
+Significant difference in the biomechanical parameters between Group 1 & 2 at the .05 level.

Test of Hypotheses

Predictions were made of how the push-up and medicine ball throw exercises peak force, MRFD, and average peak power output differed when performing the concentric only, countermovement, and plyometric methods. Typical patterns of the biomechanical parameters are displayed in Figures 22-30 and discussed in the following paragraphs. In this study the predictions made varied in comparison to the results.

Concentric Only Method

Table 4 indicates the differences in biomechanical parameters between the push-up and medicine ball throw exercises for the concentric only method. The peak force and MRFD were found to be significantly greater during the concentric only push-up compared to the concentric only medicine ball throw. However, there were no significant differences when examining the average peak power output for the concentric only push-up and medicine ball throw. In addition there were significant differences found between the groups' values of MRFD and average peak power output for the push-up exercise.

Figure 22 displays typical force patterns of the concentric only push-up and medicine ball throw exercises. From the force pattern graph the beginning of the concentric contraction was able to be determined from the increasing rise of force. In this graph not only is it shown that the peak values for these exercises differ, but also the duration of these exercises differ. When events occur and the attributes of these exercises are also displayed in figures for the results of the countermovement and plyometric methods. Figures 23 and 24 display the RFD and average power output. Figures that show RFD patterns are more jagged compared to the other biomechanical parameters. This is from the change in force occurring over a very small amount of time which produces an error component. The same is seen in the analysis of other biomechanical parameters that look at displacement over time.

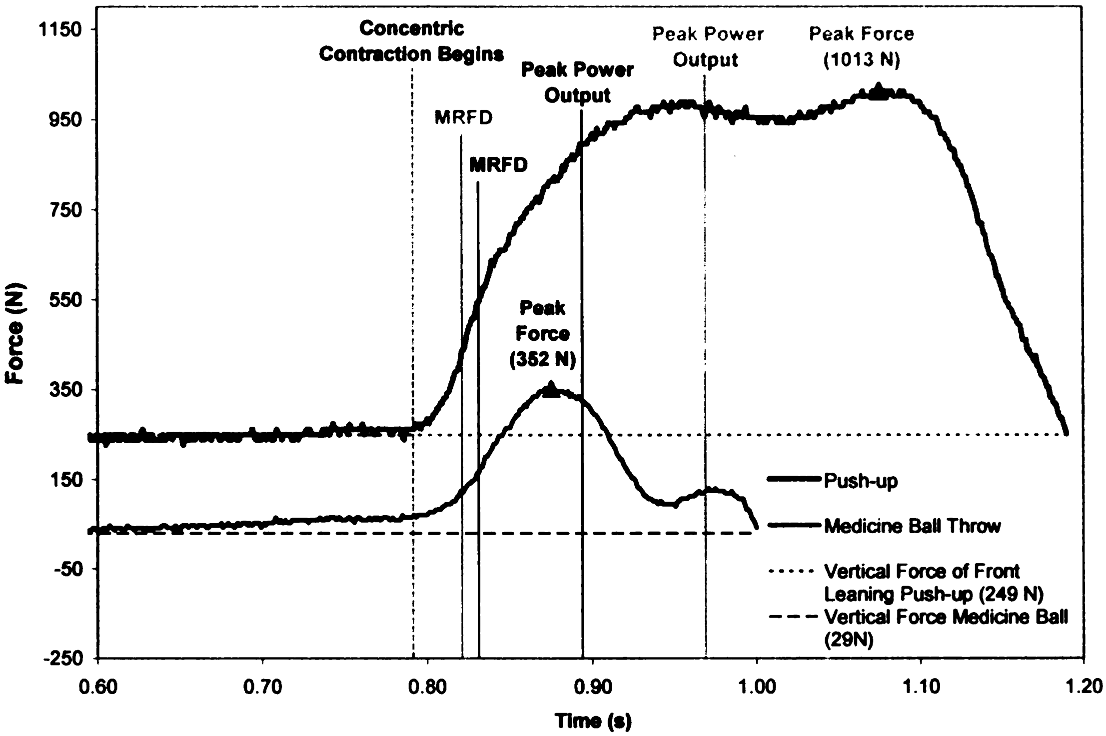


Figure 22. Typical force patterns of the concentric only push-up and medicine ball throw for participant 11PU (back lying weight = 30 kg). MRFD indicates the maximal rate of force development. The same process of calculation was also used for the concentric only medicine ball throw.

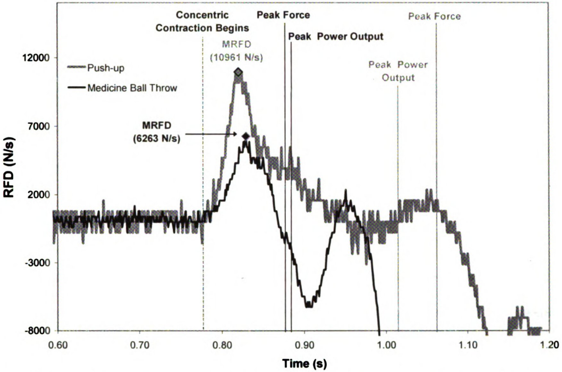


Figure 23. Typical rate of force development (RFD) patterns of the concentric only push-up and medicine ball throw for participant 11PU (back lying weight = 30 kg). MRFD indicates the maximal rate of force development.

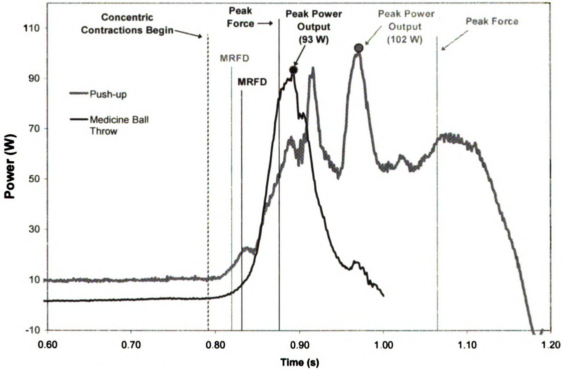


Figure 24. Typical average power output patterns of the concentric only push-up and medicine ball throw for participant 11PU (back lying weight = 30 kg). MRFD indicates the maximal rate of force development.

The hypotheses made for the concentric only push-up and medicine ball throw and the results of this study varied. Peak force was predicted and found to be significantly greater for the push-up compared to the medicine ball throw. The hypothesis that the MRFD would be significantly greater during the medicine ball throw was incorrect. The MRFD was actually significantly greater during the push-up. No significant difference was found in the average peak power output between the push-up and medicine ball throw.

Countermovement Method

Table 4 indicates the differences in biomechanical parameters between the push-up and medicine ball throw exercises for the countermovement method. The peak force and MRFD were found to be significantly greater during the countermovement push-up compared to the countermovement medicine ball throw. However, there were no significant differences found when comparing the average peak power output of the countermovement push-up to the medicine ball throw. For the countermovement method no significant differences were found to exist between groups' biomechanical parameters for both exercises.

Figure 25 displays typical force patterns of the concentric only push-up and medicine ball throw exercises. Like the concentric only method the duration of the exercises differed for the countermovement method. Figures 26 and 27 display the RFD and average power output patterns during the countermovement method for both exercises.

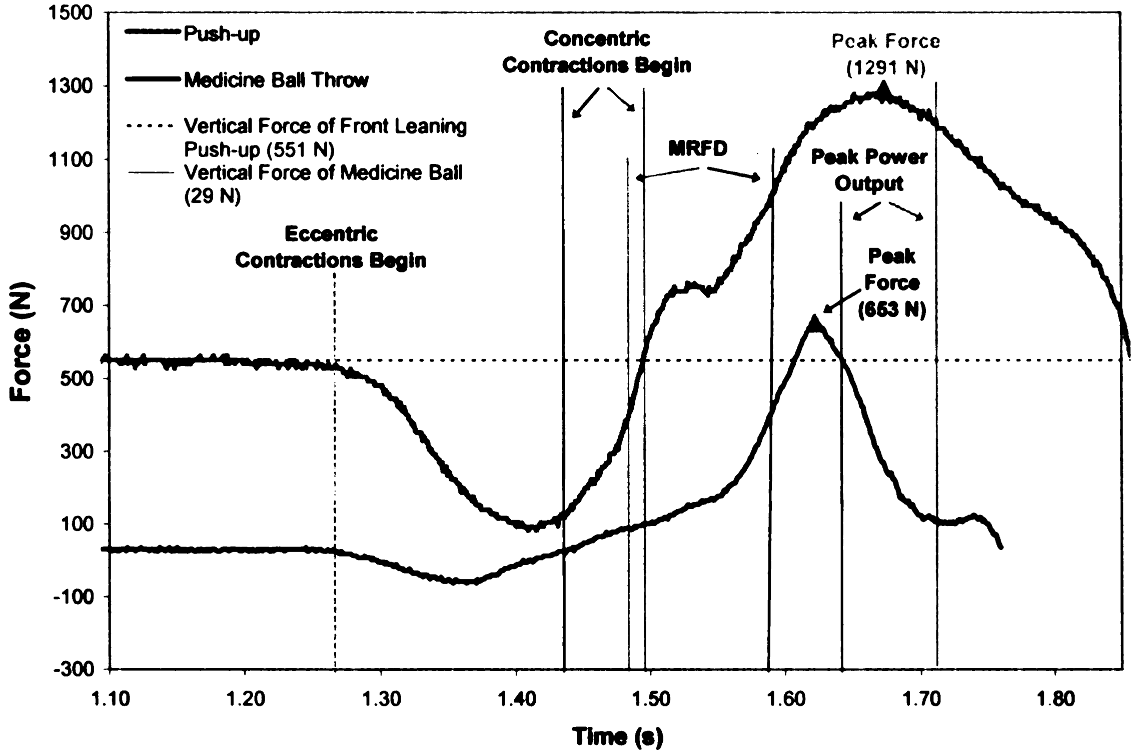


Figure 25. Typical force patterns of the countermovement push-up and medicine ball throw for participant 15PU (front leaning push-up position = 28 kg, back lying weight = 35 kg). MRFD indicates the maximal rate of force development.

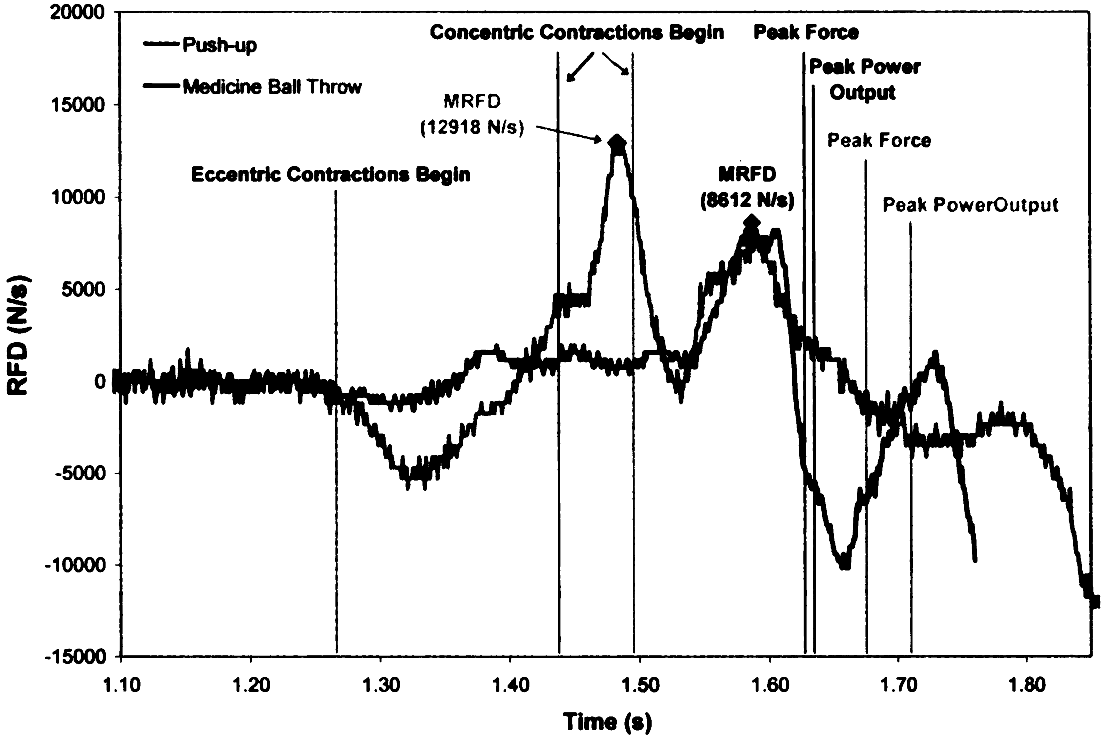


Figure 26. Typical rate of force development (RFD) patterns of the countermovement push-up and medicine ball throw for participant 15PU (front leaning push-up position = 28 kg, back lying weight = 35 kg). MRFD indicates the maximal rate of force development.

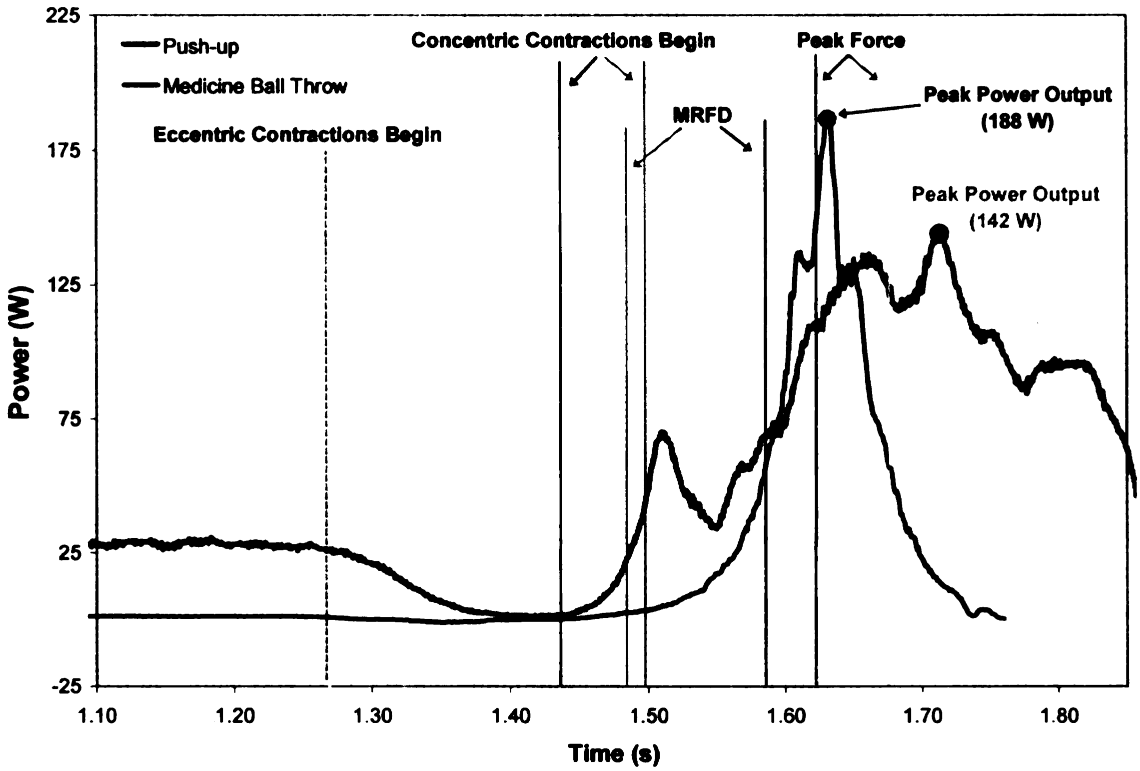


Figure 27. Typical average power output patterns of the countermovement push-up and medicine ball throw for participant 15PU (front leaning push-up position = 28 kg, back lying weight = 35 kg). MRFD indicates the maximal rate of force development.

The hypotheses made for the countermovement push-up and medicine ball throw and the results of this study varied. Peak force was predicted and found to be significantly greater for the push-up compared to the medicine ball throw. The hypothesis that the MRFD would be significantly greater during the medicine ball throw was incorrect. The MRFD was actually significantly greater during the push-up. No significant difference was found in the average peak power output between the push-up and medicine ball throw.

Plyometric Method

Table 4 indicates the differences in biomechanical parameters between the push-up and medicine ball throw exercises for the plyometric method. The peak force and MRFD were found to be significantly greater during the plyometric push-up compared to the plyometric medicine ball throw. However, there were no significant differences found when comparing the average peak power output of the plyometric push-up to the medicine ball throw. For the plyometric method significant differences were found to exist between groups' MRFD and average peak power output during the push-up exercise.

Figure 28 displays typical force patterns of the concentric only push-up and medicine ball throw exercises. From Figure 28 the eccentric contraction was determined by the initial increase in force from the contact of the hand to the force platform during the push-up or the contact of the hands to the medicine ball during the throw. The beginning of the concentric contraction was identified when acceleration values equaled zero, indicating the change in direction of movement. Like the other methods the duration of the exercises differed for the plyometric method. Figures 29 and 30 display the RFD and average power output patterns during the plyometric method for both exercises.

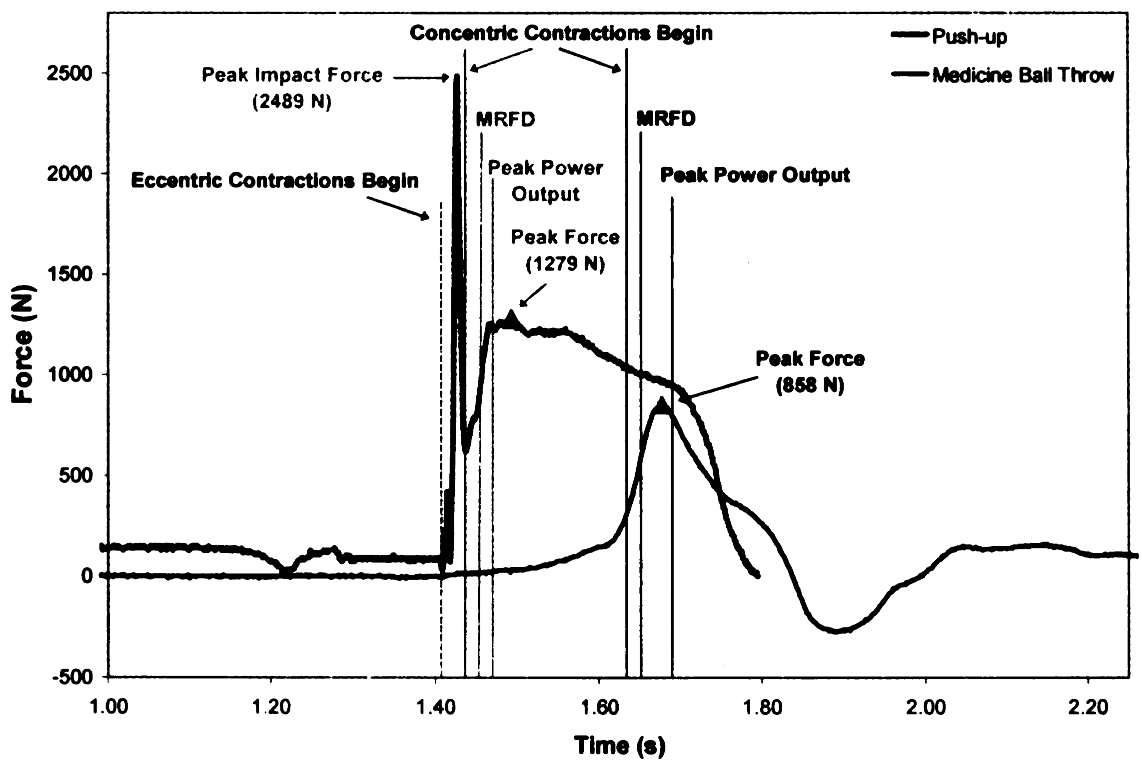


Figure 28. Typical force patterns of the plyometric push-up and medicine ball throw for participant 15PU (back lying weight = 37 kg). MRFD indicates the maximal rate of force development.

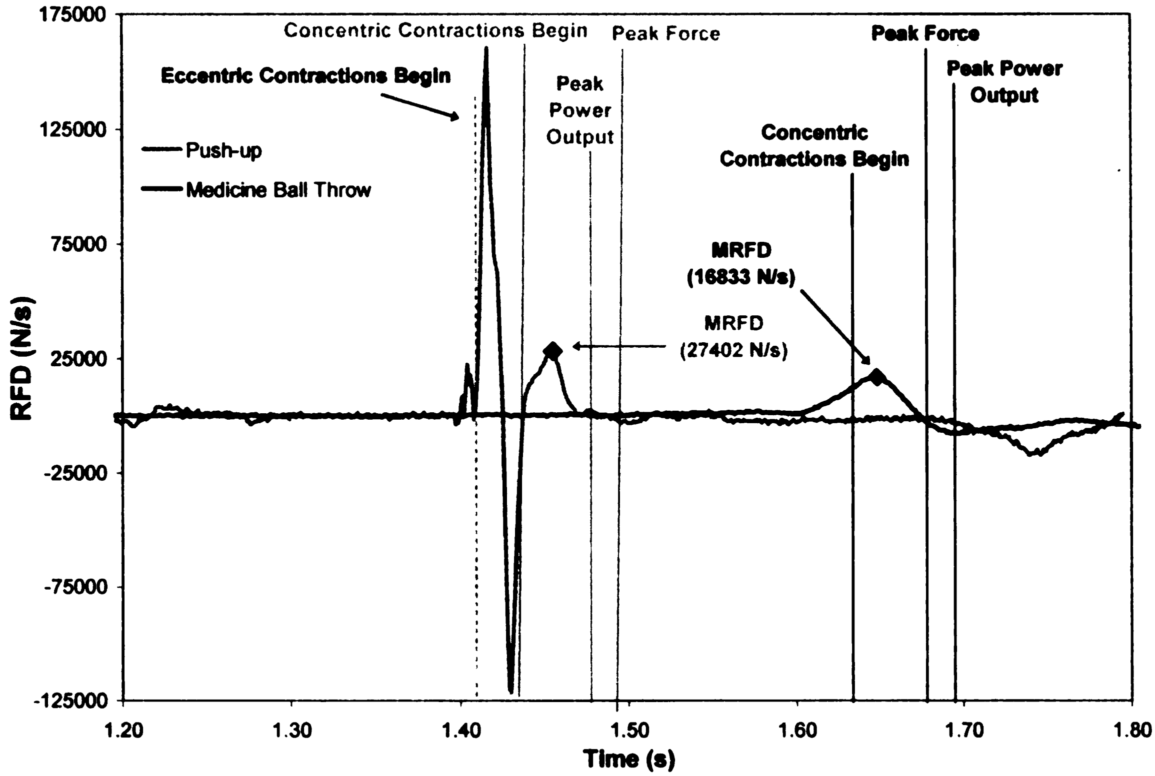


Figure 29. Typical rate of force development (RFD) patterns of the plyometric push-up and medicine ball throw for participant 15PU (back lying weight = 37 kg). MRFD indicates the maximal rate of force development. For this graph, 60 ms were examined instead of 125 ms to help display markers.

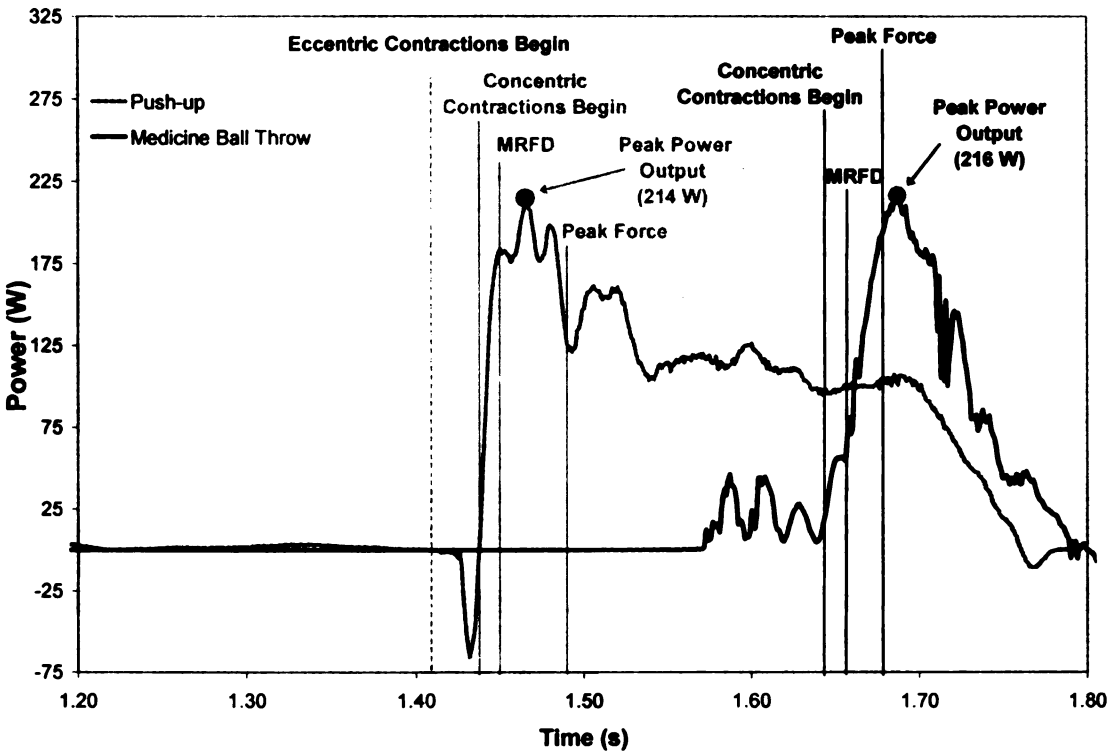


Figure 30. Typical average power output of the plyometric push-up and medicine ball throw for participant 15PU (back lying weight = 37 kg). MRFD indicates the maximal rate of force development. For this graph, 60 ms were observed instead of 125 ms to help display markers.

Based on previous laboratory work biomechanical parameters were expected to be similar when comparing the plyometric push-up to the medicine ball throw. Peak force and MRFD were found to be significantly greater for the push-up compared to the medicine ball throw. No significant difference was found in the average peak power output between the push-up and medicine ball throw.

Descriptive Data for Test of Assumptions

Table 5. Summary of T-test Results related to Peak Force, MRFD, and Average Peak Power Output for Push-up and Medicine Ball Exercises Performed as Concentric Only (CO), Countermovement (CM), and Plyometric (PLY) Methods

	CO vs CM t, p	CO vs PLY t, p	CM vs PLY t, p
Peak Force			
Push-ups (n=17)	t_{15} = 9.69, p = .00*	t_{15} = 10.41, p = .00*	t_{15} = 1.16, p = .27
Medicine Ball Throw (n=17)	t_{15} = 3.05, p = .01*	t_{15} = 6.43, p = .00*	t_{15} = 4.74, p = .00*
MRFD			
Entire Sample Push-ups (n=17)	t_{15} = 2.04, p = .06+	t_{15} = 5.48, p = .00*+	t_{15} = 4.75, p = .00*+
Push-ups Group 1 (n=9)	t_8 = 3.70, p = .00*	t_8 = 4.40, p = .00*	t_8 = 2.70, p = .01*
Push-ups Group 2 (n=8)	t_7 = .33, p = .37	t_7 = 4.15, p = .00*	t_7 = 4.73, p = .00*
Medicine Ball Throw (n=17)	t_{15} = .02, p = .98	t_{15} = 5.97, p = .00*	t_{15} = 5.75, p = .00*
Average Peak Power Output			
Entire Sample Push-ups (n=17)	t_{15} = 1.53, p = .15+	t_{15} = 4.04, p = .00*+	t_{15} = 2.19, p= .04*+
Push-ups Group 1 (n=9)	t_8 = 1.12, p = .15	t_8 = 2.76, p = .01*	t_8 = .83, p =.22
Push-ups Group 2 (n=8)	t_7 = .92, p = .19	t_7 = 3.06, p = .01*	t_7 = 2.14, p = .04*
Medicine Ball Throw (n=17)	t_{15} = 3.97, p = .00*	t_{15} = 5.50, p = .00*	t_{15} = 4.07, p = .00*

*Significant difference in the biomechanical parameters between the exercise methods at the .05 level.
+Significant difference in the biomechanical parameters between Group 1 & 2 at the .05 level.

Tests of Assumptions

Assumptions were made of how the peak force, MRFD, and average peak power output differed between the concentric only, countermovement, and plyometric methods. The results of the differences in biomechanical parameters are displayed in Table 5 and in Figures 31-33, and discussed in the following paragraphs. In comparison the assumptions made were similar to the results of this study.

Peak Force

Table 5 shows that a greater peak force was generated when using the plyometric method compared to the concentric only and countermovement methods to perform the push-up and medicine ball throw exercises. (Figure 31). However, there was no statistical significance for the push-up exercise between the countermovement and plyometric methods. In addition, results from this study indicate that the peak force values for both groups were significantly greater for both the countermovement compared to the concentric only method when performing the push-up and medicine ball throw. These results tend to support the assumptions made that peak force is going to be the greatest for the plyometric method and significantly greater for the countermovement compared to the concentric only method for the push-up and medicine ball throw. Only for the push-up exercise were there no statistical differences in peak force between the countermovement and plyometric method.

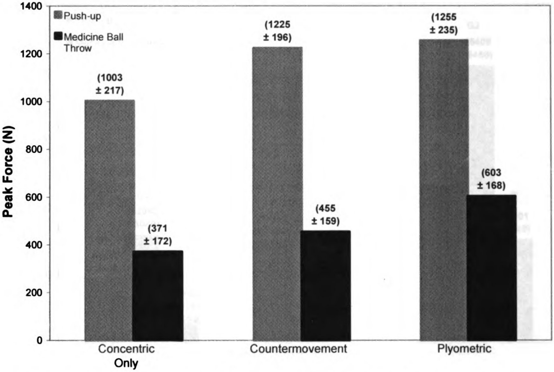


Figure 31. Comparisons of the groups' peak force values for the push-up and medicine ball throw methods.

Maximal Rate of Force Development

Table 5 indicates a significantly greater MRFD when using the plyometric method compared to the concentric only and countermovement methods to perform the push-up and medicine ball throw exercises (Figure 32). There were no statistical differences between the concentric only and countermovement methods for both exercises. These results support the assumption made that MRFD is going to be significantly greater for the plyometric compared to the countermovement and concentric only methods. However, the assumption that significant differences in MRFD would exist between the concentric only and countermovement methods were not shown in the results of this study. The only significant difference found between the countermovement and the concentric only methods was found in the push-up exercise for Group 1. There were also significant differences between the groups' MRFD for the concentric only and plyometric push-ups.

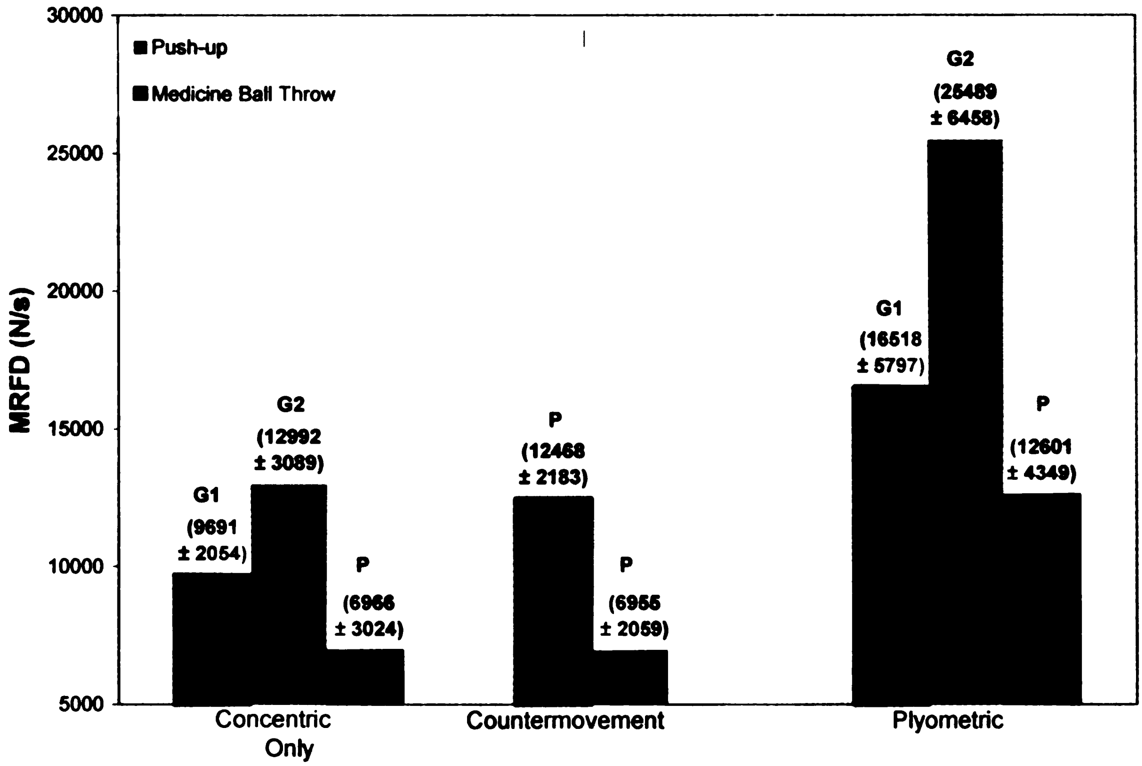


Figure 32. Comparisons of the groups' maximal rate of force development values for the push-up and medicine ball throw methods.
G1 represents data from the medicine ball group for the push-up methods.
G2 represents data from the push-up group for the push-up methods.
P represents data from the entire population.

Average Peak Power Output

Table 5 indicates a significantly greater average peak power output when using the plyometric method compared to the concentric only and countermovement methods to perform the push-up and medicine ball throw exercises (Figure 33). The average peak power output was statistically different between the concentric only and countermovement methods for the medicine ball throw but not for the push-up exercise. During the push-up, the assumption that significant differences in average peak power output would be significantly greater for the plyometric compared to the concentric only and countermovement method was shown in the results of this study. However, the assumption that peak forces were going to be significantly different between the concentric only and countermovement push-up was not a result of this study. These results support the assumption made that average peak power output was going to be significantly greater for the plyometric compared to the countermovement and concentric only medicine ball throws and for the countermovement compared to the concentric only medicine ball throw. There were also significant differences between the groups' average peak power output for the concentric only and plyometric push-ups.

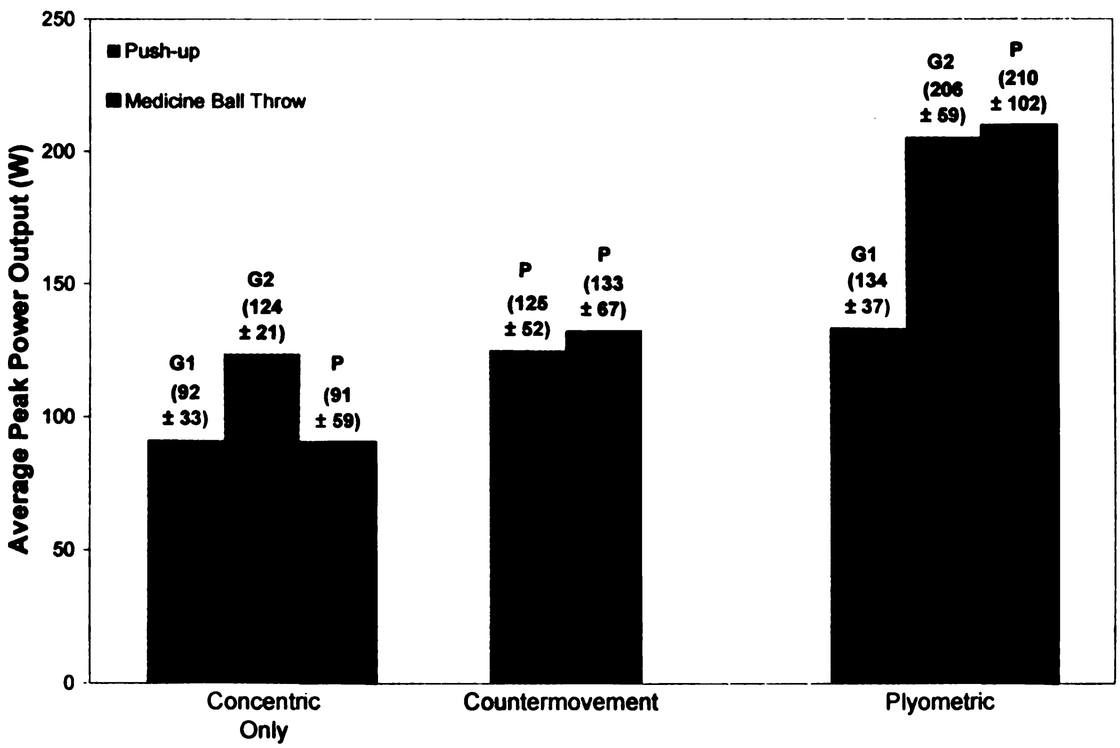


Figure 33. Comparisons of the groups' average peak power output values for the push-up methods.
G1 represents data from the medicine ball group for the push-up methods.
G2 represents data from the push-up group for the push-up methods.
P represents data from the entire population.

CHAPTER 5
DISCUSSION

Contributions to the Research Literature

Hypotheses

The results from this study show that there were significant differences in the biomechanical parameters between the two upper body exercises. However, the results and what was predicted for the study did not exactly match. Of the biomechanical parameters studied significant differences shown to occur were in peak force and MRFD, but not in average peak power output.

Hypotheses for Peak Force

The differences in the magnitude of the peak force experienced in the two exercises support the hypotheses made (Table 4). Push-up exercises performed for the three exercise methods required a significantly greater amount of explosive force compared to the 3 kg medicine ball throw. This result is supported by previous literature (Newton et. al., 1997; Schmidtbleicher & Komi, 1992); heavier resistive loads require a greater amount of peak force.

Hypotheses for Maximal Rate of Force Development

When considering the MRFD, results of this study differed somewhat from the hypotheses made about the exercises used in this study (Table 4). For all but one of the three methods of exercise, the MRFD was significantly greater in the push-up exercises compared to the medicine ball throw. Group 1 did not show a significant difference in MRFD during the plyometric push-up compared to the plyometric medicine ball throw. According to previous literature, exercises that use lighter loads rely more on the rate of force development than absolute strength to explosively perform and a substantial resistive load is required to sufficiently stimulate the MRFD (Schmidtbleicher & Komi 1992). In addition, it may be beneficial to further investigate which exercises require individuals to develop force at a higher rate, since the MRFD is reported to be trainable (Matavulj, et al., 2001; Newton, et al., 1999; Young & Bilby, 1993).

Hypotheses for Average Peak Power Output

For the biomechanical parameter of average peak power output, there were no significant differences found between the two exercises. Significant differences in average peak power output were expected between these two exercises because of the load differences between the two exercises. Values of the average peak power output from this study were similar to those of Fields, et al. (1997). The biomechanical parameters of peak force and acceleration offset one another; forces were significantly higher for the push-up exercises (Table 4), while acceleration values were higher for the medicine ball exercises (Figures 34-39). In Newton's, et al. (1997) biomechanical analysis of the bench press, there were higher velocities obtained with lighter loads. The results of Newton's, et al. study (1997) are compatible with the current study since acceleration is a derivative of velocity. However, acceleration values were not statically analyzed in the current study. In addition, acceleration values were larger for the medicine ball throw since the accelerometer was attached to a relatively smaller mass, in comparison to the much larger mass represented by the attachment of the accelerometer to the chest (Nigg & Herzog, 1994). Even though no significant differences were found in explosive power in this study, acceleration may be another crucial variable in understanding movement and its application to training the upper body, especially with plyometrics methods.

Patterns of Force and Acceleration

Vertical force and accompanying acceleration in the push-up and in the medicine ball throw should have similar patterns since force is a product of mass and acceleration and in both exercises the mass remains constant. Differences in force and acceleration patterns could be attributable to the different locations of the recording equipment during the push-up and medicine ball throw exercises (Figures 34-39). For the push-up exercise force was detected through the force platform, which was located at the participant's hands, while the accelerometer was attached to the chest of the participant. Similarly, for the medicine ball throw, the force platform was underneath the participant's shoulder blades while the accelerometer was attached to the top of the medicine ball.

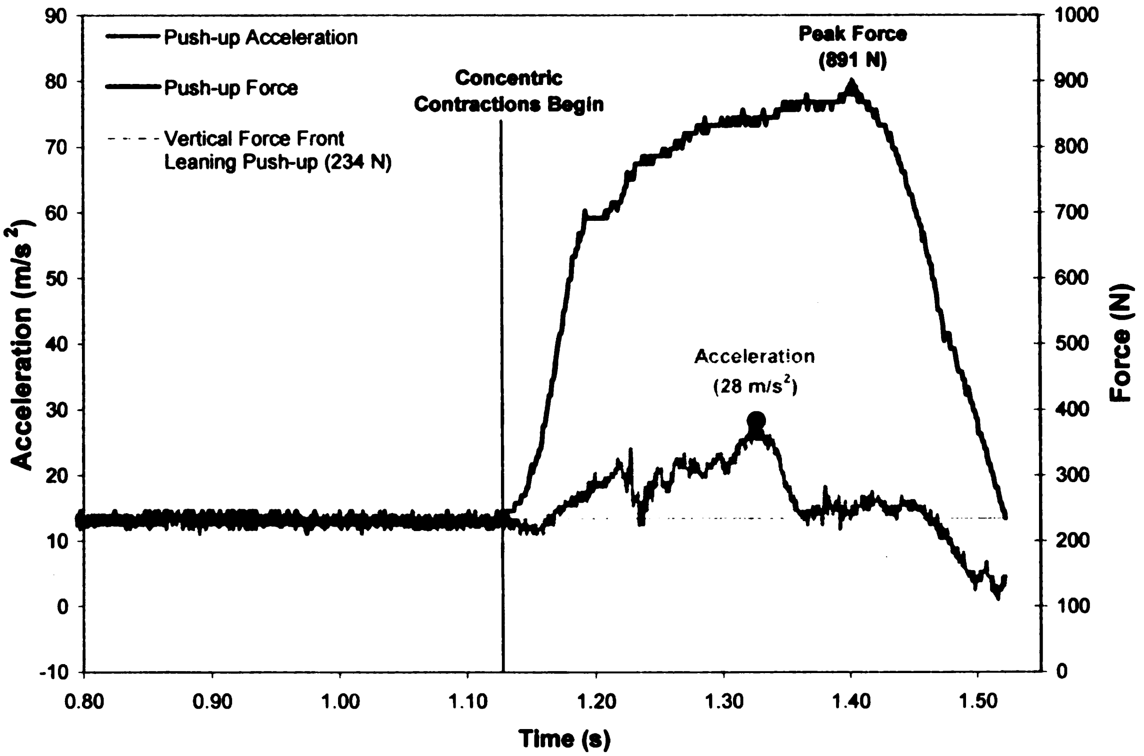


Figure 34. Typical acceleration and force patterns of the concentric only push-up for participant 15PU.

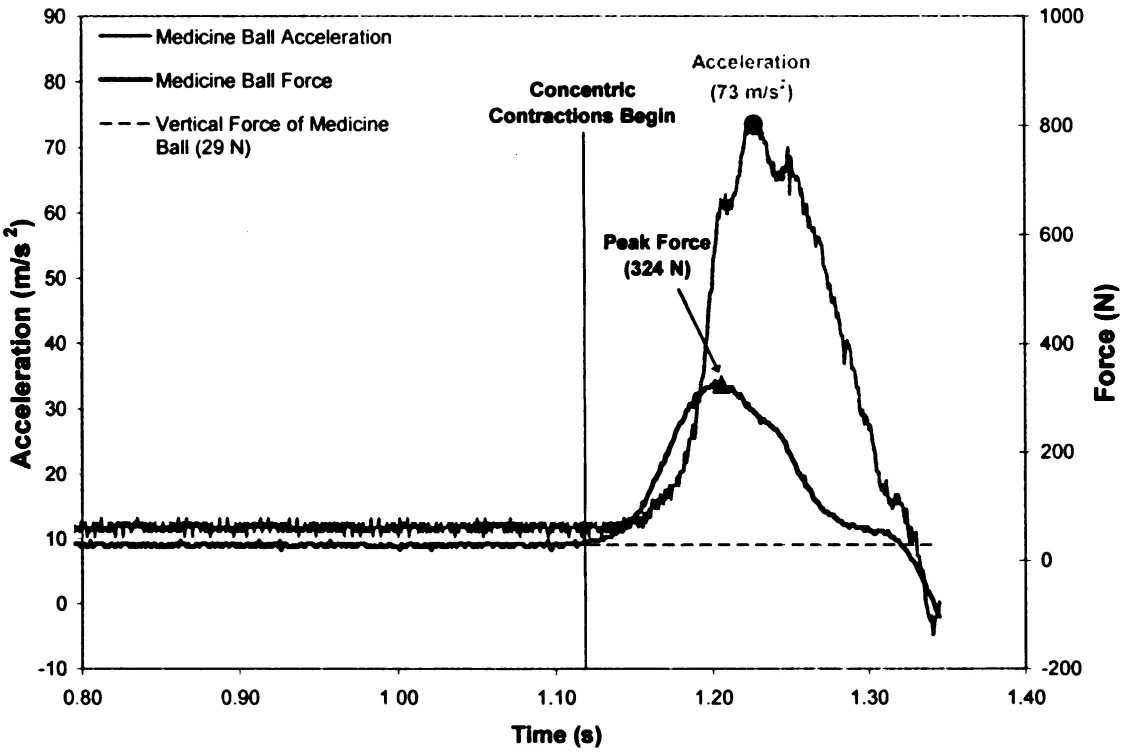


Figure 35. Typical acceleration and force patterns of the concentric only medicine ball throw for participant 15PU (back lying weight = 28 kg).

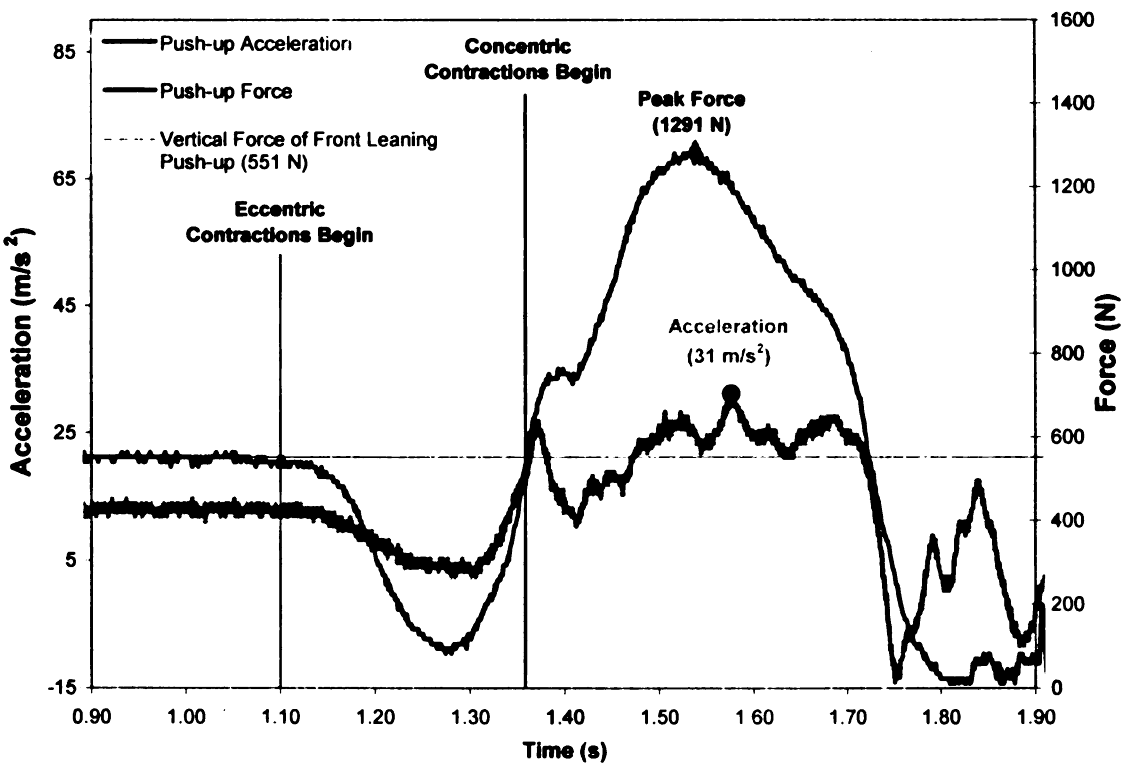


Figure 36. Typical acceleration and force patterns of the countermovement push-up for participant 15PU (front leaning position = 28 kg).

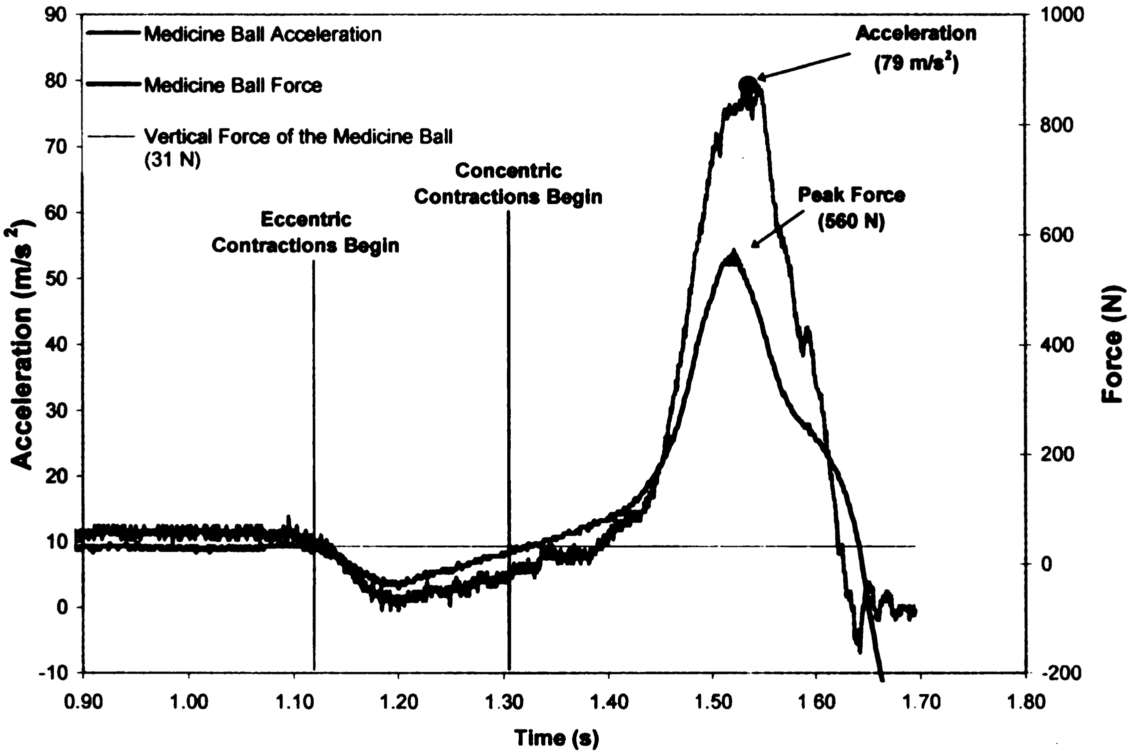


Figure 37. Typical acceleration and force patterns of the countermovement medicine ball throw for participant 15PU (back lying weight 32 kg).

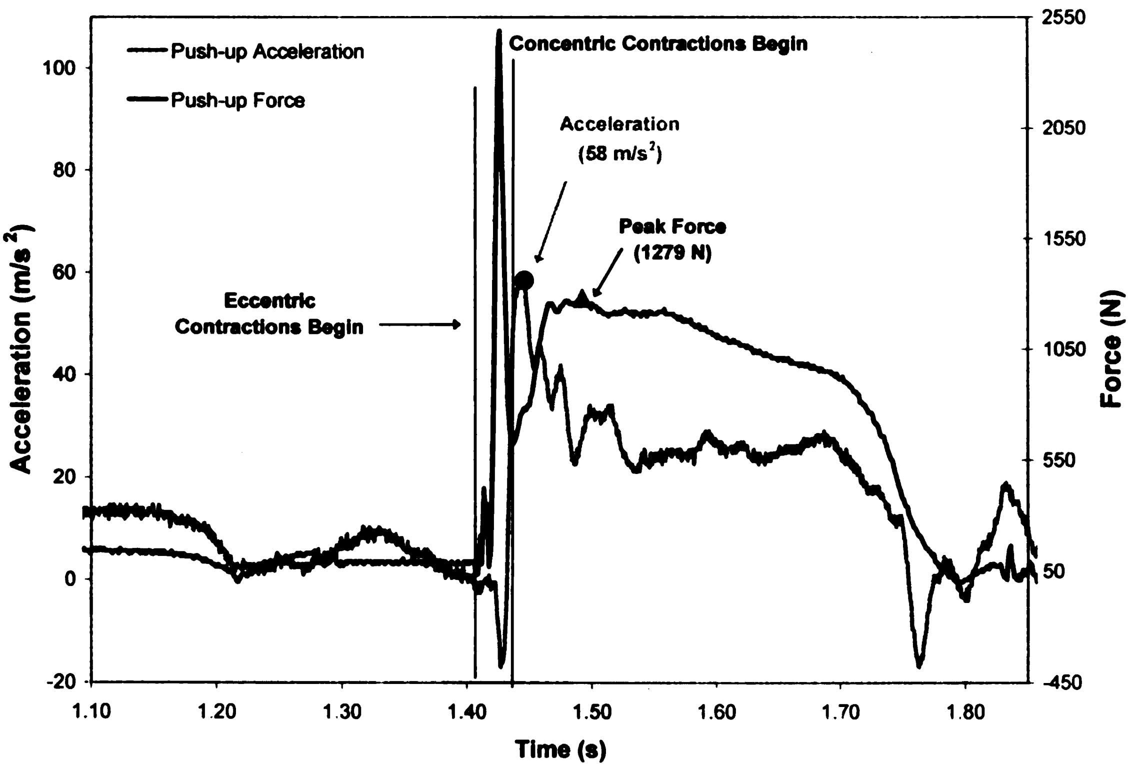


Figure 38. Typical average acceleration and force patterns of the plyometric push-up method for participant 15PU.

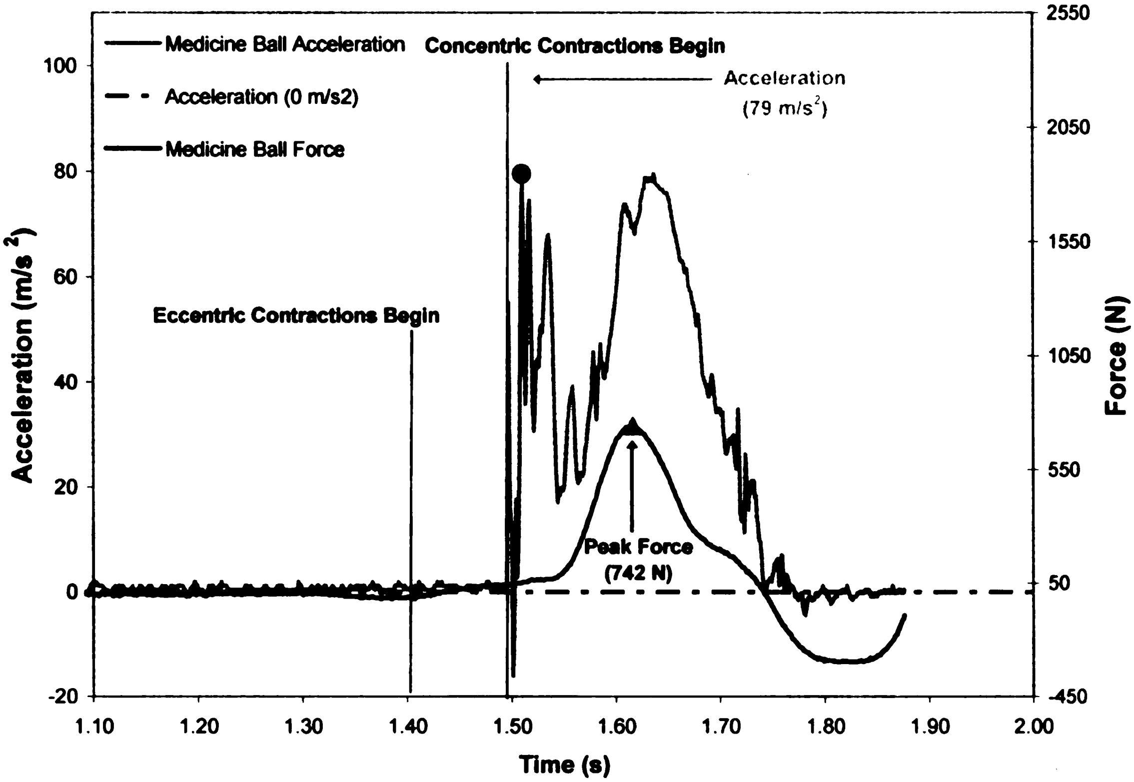


Figure 39. Typical acceleration and force patterns of the plyometric medicine ball throw method for participant 15PU.

Assumptions

Past research shows that exercise methods that utilize the SSC are going to enhance the biomechanical parameters (i.e., force and power output) in the concentric phase to a greater extent than in the concentric only method (Bobbert, et al., 1987a; Cronin, et al., 2000; Newton, et. al., 1997). In addition, plyometric exercises typically generate biomechanical variables in the concentric phase to a greater extent than countermovement exercises. In the current study, the influence of exercise methods on biomechanical parameters (i.e., peak force, MRFD, and average peak power output) supports past research.

Assumptions for Peak Force

Results of the current study indicate peak force was different between all methods of exercise. The plyometric push-up exercise produced a greater peak force compared to the countermovement push-up exercise and both methods had significantly higher peak forces compared to the concentric only method. However, for the push-up exercises, no significant differences existed in peak force between the plyometric and countermovement method for both groups (Figure 31). In both groups, the highest peak force during the medicine ball throw exercise was for the plyometric method (Figure 32). From this information, it could be generalized that explosive upper body exercises that rely on the SSC are going to develop higher magnitudes of force in comparison to concentric only methods.

Assumptions for Maximal Rate of Force Development

Significant differences in MRFD were found when using different types of exercise methods. During the push-ups, results varied according to group. Group 1 showed significant difference in the MRFD for all methods, with the plyometric method producing the greatest MRFD. Group 2's differences in the MRFD were only significant between the plyometric and countermovement method, and between the plyometric and concentric only method. However during the medicine ball throw, significant differences were found with the plyometric method when it was compared to the countermovement or concentric only methods for the subgroups. Since upper body plyometric exercises require a greater MRFD, plyometric exercises could be beneficial in training athletes who require a high rate of force development during sports activities.

Assumptions for Average Peak Power Output

For both the push-up and medicine ball throw significant differences existed in average peak power output when different methods of exercise were used. The average peak power output was significantly greater during the plyometric method when compared to the countermovement and concentric only methods (Figures 35 & 36). Exercise trials with the plyometric movement for either exercise required a greater amount of power to explosively perform compared to the concentric only or countermovement methods. Plyometric push-ups, performed in conjunction with upper body training, have been shown to improve performance (i.e., distance of medicine ball throw) more so than traditional training (Crowder & Jolly, 1992).

The eccentric phase of countermovement exercises typically results in enhanced performance during the concentric phase in comparison to the performance parameters during the concentric only method. Even though the biomechanical variables measured in this study were higher during the countermovement method for both exercises, only the peak force was consistently and significantly higher during the countermovement method (Figures 31 & 32) compared to the concentric only movement. According to literature (Cronin, et al., 2000; Newton, et. al., 1997), exercises that involve the SSC. produce higher average velocity, force, power output, and electromyography (EMG) activity than concentric only movements. To produce higher levels of force, a countermovement or SSC. is required.

Implications

The goals of this study were to provide practical and scientific information to strength coaches and exercise scientists, as well to personal trainers and individuals who perform resistance training.

Implications for Strength Coaches

Information gained from this study holds implications that are practical for coaches who train athletes. This relates to the order, mechanics, and kinetics of exercise.

Order of Exercise

One idea that the results of this study suggests is that the order in which upper body exercises are completed may significantly affect an individual's performance during a testing or training session. This idea is based on significant differences between the group's biomechanical performance parameters (i.e., MRFD and peak average power output) during the push-up exercises (Table 4), even though the groups were homogeneous on physical parameters (i.e., anthropometric and strength measures; Table 3). Group 2 (i.e., group that performed push-up exercises first) was able to achieve a greater rate of force development and produce a greater average peak power output compared to Group 1 (i.e., group that performed medicine ball throw exercises first). Group 1 may have been, to a certain degree, fatigued after the medicine ball exercises resulting in decreased performance during the push-up exercises. In this study, it might have been beneficial to give longer rest intervals between exercise trials, so if fatigue were a factor to biomechanical performance parameters it would be of a lesser extent. Note that the push-up exercises placed a heavier load on the upper extremities than the medicine ball exercises. Information in the scientific literature on order of exercise is mixed. One study, that involved the use of isometric training before a power movement, found that the participants' power output was enhanced (Gullich & Schmidtbleicher, 1996). Another training study that used heavy dynamic resistive training (i.e., 5 RM bench press) or explosive push-ups prior to testing the power output of explosive push-ups found no significant difference in power output (Hrysomallis & Kidgell, 2001). Whether or not the order of exercise influences training adaptations over a period of time needs to be further investigated. Information on how the order of upper body exercises influences biomechanical performance parameters could be important to how training programs are designed. Training programs that prevent athletes from optimal performance could interfere with their improvement or possibly their sport skill performance if the theory of training specificity holds true. The order of exercise during training could also help protect athletes from potential injury. In a training session, if athletes are vigorously training their chest and upper extremities, plyometric push-ups at the end of the training session could be difficult to perform and potentially injurious.

Exercise Mechanics

In this study it was observed that it was easier (i.e., from a skill perspective) for participants to perform the mechanics of the plyometric push-up compared to the plyometric medicine ball throw. This could be due to the difference in load (i.e., upper body weight in the push-up is considerable greater than the 3 kg medicine ball). With the plyometric push-up, when participant's hands made contact with the mouse pads, they were unable to immediately stop the downward motion and were forced to descend a short distance before the concentric motion started. This motion seemed to be more natural and less skill dependent compared to the plyometric medicine ball throw. During the plyometric medicine ball throw, participants demonstrated uncertainty about when to start pushing against ball. Typically the participants took one of two approaches. They would either try to "bump" the ball upward or let the ball descend down close to their chest before moving it upward. Due to the shape of the ball and the ball not being as stable as the ground, this may have affected the participants' performances. During some of the trials, there was a noticeable rotation on the ball after the throw. In these cases the data was not used. However, rotation of the ball could possibly indicate the ball being received in an awkward position (i.e., not in the center of the chest) for participants to catch and subsequently project upward. Or, maybe one hand was compensating for the other hand when receiving the ball because of the position of the hands on the ball, causing one hand to push more than the other. Possible solutions to help prevent mechanical problems and variations in the medicine ball throw include: more clearly explaining the movement pattern associated with plyometric exercise, providing additional practice in the medicine ball throw before testing, providing a target directly above the chest, and using a medicine ball of sufficient weight heavy enough to stimulate an appropriate SSC response.

Kinetics of Performance

Another result of this study that may be beneficial to coaches who strength train athletes, is to consider the significant kinetic differences between the push-up and medicine ball throw methods. These kinetic differences clearly indicate that push-ups, regardless of the methods used, require significantly more peak force and a higher MRFD to perform than supine medicine ball throws with a 3 kg ball (Table 4). This information could be of value in two ways. First, athletes who are beginning plyometric training should start with exercises that have less impact force. Using an exercise that requires less force (i.e., less massive medicine ball throw) should be easier for the beginner to manage and it will likely be safer. It also may be beneficial to train novice exercisers in a progressive order of exercise methods beginning with the concentric only, progressing to a countermovement, and, finally, to the plyometric method. On the other hand, the plyometric push-ups may be more beneficial to the experienced weight trainers who have developed considerable upper body strength. In addition, plyometric push-ups requiring high levels and rapid development of force may be more compatible to the demands of sport. One study that used highly trained athletes from different sports showed that each athlete group had a maximum power output under different load conditions. (Izquierdo, Hakkinen, Gonzalez-Badillo, Ibanez, & Gorostiaga, 2002). If the principle of "specificity of training" holds for exercise training, then appropriately selecting exercises and methods of performing these exercises may be beneficial. In addition, research has shown that the load and type of training used can influence athletic performance (Harris, et al., 2000; Wilson, et al., 1993).

Implications for Exercise Scientist

It is important for exercise scientists to find and show the relevance of science in sports and sports training to those who coach and train. Results from this study should be beneficial to exercise scientists investigating sports biomechanics. This study provides a base of information on the biomechanical differences between two similar explosive upper body exercises (i.e., push-up and medicine ball throw) performed under three methods (i.e., concentric only, countermovement, and plyometric method) that are used in physical training. There is a need to further explore the specificity of training.

Exercise Differences in Biomechanical Variables

This study implies that biomechanical parameters differ in the performances of similar explosive upper body exercises. This finding supports past research (Cronin, et al., 2000; 2002; Newton, et al., 1996; Newton et. al., 1997). Two parameters from this study exhibited significant differences between the exercises when using the same exercise method (Table 4). Peak force and MRFD were significantly higher in the push-up exercise when compared to the medicine ball throw. This difference is probably attributable to the load used. This supports the results of Blackard, Jensen, and Ebben's study (1999). In addition, the current study and studies of others (Cronin, et al., 2000; 2002; Newton, et al., 1996; Newton et. al., 1997) agree that methods of exercise influence magnitudes of biomechanical parameters and when maximum values occur within phases (i.e., concentric and eccentric) of performance. Although acceleration values were not statistically analyzed in this study, they appear to be different when comparing the methods used for the push-up and medicine ball throw exercises (Figures 34-39). Information gained from research on methods of training may be important in scientifically establishing training methods.

Specificity of Training

The exercises used in this study, compared to exercises used in most other research and forms of training allowed individuals to accelerate through the full range of motion, similar to that of actual explosive sports movements of the upper body (e.g., golf drive, softball throw, tennis serve, football pass, javelin throw, and baseball pitch). In traditional exercises (i.e., countermovement resistive training) the amount of time to complete a repetition is typically shorter than in the plyometric exercise. If training adaptations are specific to movement and an athlete's sport skill efficiency specific to training, the effect of using the plyometric method in training may enhance one's skill efficiency to a greater extent (e.g., a weight lifter's ability to press more weight during a bench press, a football player's upper body force production during a block, a shot putter's throw for distance). However training specificity exercises, intended to enhance one's sport skill efficiency, are likely to differ biomechanically from the actual sport movement. If exercises require the use of movement patterns or biomechanical parameters that are more closely associated with the biomechanical patterns associated with movement in sport skills, then sport skill efficiency maybe enhanced to a greater extent. Even though most research supports one's performance or skill efficiency being enhanced to a greater extent through the use of sport or movement specific training, there still remains debate (Blazevich & Jenkins, 2002; Bloomfield, et al., 1990; Harris, et al., 2000; Jones, et al., 1999; Matavulj, et al., 2001; Newton & McEvoy, 1994; Newton, et al., 1999).

Implications for Personal Trainers and Individuals Who Perform Resistance Training

Information from this study may be useful to personal trainers and those who engage in upper body resistive training. The plyometric exercises used in this study may be of interest to those who use resistance training because of the possible training effect on performance and in this study they did not cause any injuries in the participants.

Effects of Plyometric Exercises

For healthy individuals interested in starting these exercises, as previously described in the section on *Implication for Coaches*, an order of progression of methods (i.e., from concentric only, to countermovement, to plyometric), going from least to greatest force demands, may be ideal (Figures 34-39). Plyometric exercises require a greater amount of force and a faster rate of force development than other traditional exercises. There is support for upper body plyometric training or training with faster concentric accelerations enhancing force production to a greater extent than traditional methods (Jones, et al., 1999; Vossen, et al., 2000). Again, more research is needed to understand how various methods of exercise influences performance.

Risk of Injury

This is an important finding because of concern for injury in plyometric exercises. Exercises were found to be relatively safe in experienced weight trainers if proper exercise techniques were used. Out of the 17 healthy resistant trained participants in this study, only one reported a temporary mild pain in the wrist during testing of the plyometric push-up. No other problems were reported or observed during testing. Before starting these exercises it would be important to seek proper training on exercise technique.

Recommendations

Recommendations from the conduction of this study are directed toward improving future studies looking to replicate this study or aspects of this study. Recommendations that future studies should consider are based on ways to contributions to scientific knowledge, methods and practice.

Scientific Knowledge

Based on the review of literature and the results of this study there are additional suggestions that may help future studies contribute to the scientific body of knowledge in exercise science. Scientific knowledge could be advanced in exercise science by focusing research on various exercise methods, the influence of training on performance and sport skill efficiency, the analysis of other biomechanical parameters, and the relationship of plyometric upper body exercises to rehabilitation.

Exercise Methods

This study took a step toward the understanding of ways in which kinetic variables are influenced by different types of exercises and methods. Results from this study indicate distinct differences in biomechanical parameters between two similar exercises. Future studies should investigate how different training methods (e.g., concentric only, countermovement, eccentric and plyometric) affect performance. In addition, it would be interesting to know how changes in the mass of the medicine ball would influence patterns of biomechanical output parameters.

Influence of Training on Performance and Sport Skill Efficiency

Lower body training studies have shown biomechanical parameters and sport skill efficiency (i.e., jumping ability) to be altered through training (Hewett, et al., 1996; Matavulj, et al., 2001; Newton, et al., 1999). In regards to further development of the current study on upper body exercises, it would be of interest to determine the influence of training programs using various methods of training on biomechanical variables and sport skill efficiency. Additional biomechanical studies may enhance the body of knowledge in exercise science and help bridge the gap between researchers and practitioners.

Analysis of Other Biomechanical Parameters

Researchers have shown that biomechanical parameters are significantly influenced by different exercises (Blackard, et al., 1999; Blazevich & Jenkins, 2002; Bobbert, et al., 1987a; Cronin, et al., 2000; 2002; Delecluse et. al., 1994; Escamilla et. al., 2001; Izquierdo, et al., 2002; Newton et. al., 1997; Young, et al., 1999a). On the other hand, Bloomfield, et al. (1990) showed that the results of performance were more closely associated with anthropometric measures than exercise training in elite water polo players. Additional research on the importance of biomechanical performance parameters in comparison to anthropometry is warranted.

Relationship of Plyometric Upper Body Exercises to Rehabilitation

It was reported (Davies & Matheson 2001) that, especially for the upper body, there is a lack of biomechanical information in regards to plyometrics. Future studies that provide biomechanical information of upper body plyometrics may be of value to those in rehabilitation or preventive injury training. Providing biomechanical information (e.g., acceleration, impact force, torque) on the shoulder girdle and upper extremity during exercise may be useful to therapists for their selection or rejection of plyometric exercises for rehabilitation. This might be beneficial to athletes who need to progress too more intense exercises before returning to sport activities.

Methodology

Continuing research in this area should aim at minimizing variance of the results. From this study there were three ways in which variance could have been reduced. Suggestions for reducing variance relate to the population studied, participants receiving more practice and coaching prior to data collection, and a standard method in which biomechanical parameters are recorded.

Homogenous Population

To statistically enhance the ability to obtain differences between exercises, it would have been ideal to have a larger sample size. However, in some biomechanics studies, where data collection and coding are time consuming, relatively smaller sample sizes have been acceptable. The number of participants in this study is similar to that of other studies of biomechanical variables (Newton, et al., 1996; Newton et. al., 1997). In addition, the population used in this study was homogeneous on selected anthropometric and strength measures; no significant differences were found between anthropometrical and strength measurements in the two subgroups and their performances were similar in each of the two exercises. Although for future studies it would be ideal to have a more homogenous population (i.e., sport and resistant training background). Backgrounds between the participants differed; some had participated in collegiate sports (plyometric training experience) and even though there were similarities in their training regiments (i.e., number of repetitions and sets) there were differences (i.e., types of exercises they used and training duration). Even though there were no significant differences found between the two groups, differences in measurements taken in weight and relative strength between the two groups were relatively high.

Additional Coaching and Practice

To those who are looking to do additional research with the plyometric medicine ball throw, additional coaching and practice would be beneficial to those who have no previous experience with plyometric exercises. The plyometric medicine ball throw appeared to require more skill to perform than the plyometric push-up. Bobbert's, et al. previous study (1987a) affirmed that two or three practice trials were sufficient for participants to correctly perform plyometric jumps and the same was found in this study for the plyometric push-ups. However, when using lighter loads for plyometric exercises, more practice and coaching may be needed to help individuals who are inexperienced.

Standard Method of Recording Biomechanical Parameters

From the review of literature and this study it would be ideal to have a standard method to further develop the area of exercise science and help minimize error. It was difficult to make a comparison of the reviewed studies' results and the results of this study, since different recording methods were used to calculate biomechanical parameters. For instance, in other studies the participant would be on the force platform while the force platform was set to zero. This in turn, affects the value of force output recorded during the exercise trial since the weight of the participant is subtracted out of the force calculation. Having a standard method to record biomechanical parameters may increase the body of knowledge in biomechanics by helping exercise scientist build on to previous research.

Practice

There were valuable experiences gained from this study that would be of benefit to future biomechanical research on upper body exercises. Practices to consider are the number of force platforms used, identification of the concentric phase during the plyometric medicine ball throw with an accelerometer, and the influence of medicine balls of various weights on biomechanical performance parameters.

Number of Force Platforms

With the size of force platform used in this study getting an individual to perform push-ups with both hands on one force plate would have been difficult. It has been recommended (Baca, 1999) to use two platforms to allow a more accurate reading of force impact and production. Therefore, the use two force platforms, if they are available, or use one, if the size of the force platform is big enough to accommodate the width of both hands during the exercise is recommended.

Identifying the Concentric Phase with an Accelerometer during Medicine Ball Throw

The accelerometer was accurate and reliable, but it was difficult to determine when the concentric phase started during the plyometric medicine ball throw. The accelerometer had perturbation when the ball made contact with the hands from the 1 m drop. Two suggestions may help future studies. Attach the accelerometer to a place other than the ball. It may be ideal to attach the accelerometer to the wrist or create a device that would connect to the hands during the exercise trial. Another option would be to film each trial with a high-speed camera and timing lights. This may allow one to examine ball movement and acceleration recordings simultaneously. However this suggestion may also be problematic since positional errors are magnified when calculating velocity and subsequently calculating acceleration.

Influence of Medicine Balls of Various Weights on Biomechanical Parameters

Finally, for the upper body it would be of interest to understand how biomechanical variables correlate to different upper body exercises and loads. Using a heavier weighted ball will likely require the production of biomechanical variables that are more similar to that of the push-up exercise (Blackard, et al., 1999). A lighter medicine ball was chosen on the basis of common guidelines (Baechle & Earle, 2000; Chu, 1998) and concern for safety. If training specificity occurs, then varying the loads of the medicine ball for exercises may help coaches select a weight that would augment certain biomechanical variables to a greater extent in athletes who are of different abilities and participate in different sports.

Conclusions

There are several conclusions that can be drawn from this study. The conclusions made relate to the results of this study, the implications the results have to those in the exercise science field, and recommendations for future studies.

Push-up methods are going to generate a greater peak force and MRFD when compared to the same methods of the 3 kg medicine ball throw when performing explosively. When comparing methods, the methods that use the SSC are going to generate significantly greater biomechanical variables. The only exception to this was when the MRFD was compared between the concentric only and countermovement methods. Between the methods that use the SSC the plyometric method is going to produce significantly greater biomechanical variables than the countermovement method, except for the peak force during the push-up.

In addition, implications were made for coaches, exercise scientists, and personal trainers. For strength coaches, when performing multiple explosive exercises in a training session, consideration should be taken to the order in which explosive exercises are performed. Because there were participants in this study that had never performed plyometric exercises it may be beneficial to provide additional coaching and practice to athletes who are new to plyometrics, especially for the lighter weight medicine ball throw. Coaches should also consider the age and the level of athlete they are working with when choosing which upper body plyometric exercises to use. Some exercises that cause higher impact forces and require higher peak forces may not be suitable for athletes whose strength has not yet developed. For exercise scientists, this study shows that there are significant differences in biomechanical parameters when comparing these two exercises and exercise methods. There should be further investigation to see if there is a training effect and if that training effect carries over into efficiency of sport skill when using these exercises and exercise methods. For personal trainers, upper body plyometric exercises may be beneficial to enhancing a client's strength parameters. In this study, these exercises were shown to be safe for those who had been participating in weight training for an extended period of time when shock absorbent surfaces were used. In addition, an order of progression may be beneficial when starting clients with these exercises.

In closing recommendations to improve the quality of similar future studies, researchers should consider how their work is going to contribute to the body of knowledge in exercise science and the methods and practices that are being implemented. The body of exercise science would benefit from future investigation of the effects of training on sports skill efficiency and analysis of other biomechanical variables as they relate to performance. Methods to implement would be to include larger and more homogenous populations who have used the exercises in the study if the intention of the study is based on performance rather than coaching. In practice, careful consideration must be taken when selecting the use of equipment for recording biomechanical information and the interpretation of that information or the results of the study and its contribution to exercise science may be inconsistent.

APPENDICES

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Table 6. Training Studies of Concentric Only Exercise

No significant post training results differed between [illegible]

*Table abbreviations are as follows:
btwn = between. Δ = change. deg/s = degrees per second. ↑ = increase. ISOK = isokinetic. ISOM = isometric. max = maximal. PE = physical education. rad/s = radians per second. reps = repetitions. SIG = significant.

Author, Year	Participants	Methods	Results
Caiozzo, et al., 1981	• 12 male and 5 female, sedentary, 20-38 yrs	• Tested max* knee extension torque pre/post-testing @ 4 velocities (0-5.03 rad/s) • Assigned to 1 of 3 groups: control, slow (1.68 rad/s), & fast (4.19 rad/s) • 2 sets of 10 max reps, 3x/wk, 4 wk	• Slow training ↑ torque at all speeds by 14% (0 &.082 rad/s) by 8% (1.68-3.35 rad/s) & 5% (4.19 rad/s) • Fast training improved torque by 5% @ most speeds except ISOM & by 8.8% @ training speed
Coyle, et. al., 1981	• 22 physically active, college age, males 21-27 yrs • No previous training 2 yrs • 5 groups, (control, placebo, fast, slow & mixed)	• Performed knee extensions, 3x/wk, 6 wks, kept work same by changing sets and reps for various speeds • Slow, 60 deg/s, 5 sets of 6 max reps • Fast group, 300 deg/s, 5 sets of 12 max reps • Mixed group did half work of slow & fast group	• Placebo group ↑ torque by 8% ISOM • Slow group ↑ peak torque by 20, 31, to 10% @ 0, 60 & 180 deg/s • Mixed group ↑ peak torque by 19, 23, 8 & 16% @ 0, 60, 180 & 300 deg/s • Fast training ↑ peak torque by 24, 15.1, 16.8 & 18.5% @ 0, 60, 180, & 300 deg/s
Kanehisa & Miyashita, 1983	• 21 males ~ 24 yrs • Assigned to 1 of 3 groups, slow (1.05 rad/s), intermediate (3.14 rad/s) & fast (5.24 rad/s)	• Measured max knee extension torque & power @ 5 speeds (1.05 - 5.24 rad/s) • Calculated work & power • 3 sets, 2 min rest, slow group 10 reps, intermediate group 30 reps & fast group 50 reps • 6 days/wk, 8 wks	• Slow group ↑ SIG power @ all speeds, ↑ was less as speed ↑, 22, 15.8, 7, 7, & 7% from 1.05-5.24 rad/s • Intermediate group similar results 15, 15, 19, 21 & 21% from1.05- 5.24 rad/s • Fast group ↑ at fast speeds 7, 17, 20% from 3.14-5.24 rad/s

(Table 6 continued)

Behm & Sale, 1993	• 8 male & 8 female PE students, ~20 yrs • One group, opposite leg served as control	• Perform max dorsiflexion ISOM or ISOK • Trained 16 wks, 3 days/wk, 8 wks, 3 wk break, 8 wks • Performed 3 (1st), 4 (2nd) and 5 sets (remaining weeks) 10 max ballistic movements, 2-3 min rest btwn sets	• Both types of training produced high velocity response to training • ↑ MRFD by 26% • ↑ peak torque by 38%
Prevost, et al., 1999	• 18 males, 19-35 yrs • Beginning weight training students, 3 wks of training • 2 groups, fast (4.71 rad/s) & slow (0.52 rad/s)	• Tested knee extension peak torque 3x • Warm-up of 10 reps at 1.57 rad/s • Peak torque measured at 4.71, 2.62, & 0.52 rad/s, 3 max effort contractions @ each speed 20 s rest btwn reps and minute rest btwn sets • Each group performed 3 sets of10 reps for 2 days	• No SIG Δ in peak torque btwn groups btwn 2 tests • Test 3 fast group SIG ↑ (22.1%) mean peak torque at training speed

Table 7. Biomechanical and Training Studies of Countermovement Exercise

[redacted]

*Table abbreviations are as follows:
Δ = change. 1RM = 1 repetition maximum. IIa = Type IIa muscle fibers. IIb = Type IIb muscle fibers. AA = African American. BP = Bench press. btwn = between. CON = concentric. CA = Caucasian American. $\downarrow$ = decreased. ECC = eccentric. Fri = Friday. $\uparrow$ = increased. ISOK = isokinetic. ISOM = Isometric. max = maximal. ms = millisecond. min = minute. Mon = Monday. PLYO = plyometric. PU = push-up. reps = repetitions. s = second. SIG = significantly. wk = week(s). yr(s) = year(s)

Author, Year	Participants	Methods	Results
Bloomfield, et al., 1991	• 21 men, under 19 men's water polo teams ~ 18.5 age	• 12 – upper body resistance training for 8 weeks, 3X/week • Others served as control • Continued swimming routine 3 X/wk • Nautilus machines, overhead press, behind head press, decline bench, pullovers, latpulls, flys, bicep curl and tricep press • 12-15 reps / 3 sets for primarily upper body • Camera measured throwing velocity at 100 frames/ s • Recorded anthropometrical variables of weight, biacromial width	• Anthropometrical variables of length, width, mass signify relationship to throwing velocity • No relationship of throwing velocity w/ mesomorphy, flexibility, or skin folds • Upper body strength tests related to throwing velocity • No change in overhead throwing velocity
Young & Bilby, 1993	• 18 male subjects , 19-23 yrs • No previous resistance training	• Pre/post-test 1 RM machine squat • 2 groups, 8 in fast • Trained 3X/wk, 7 ½ wks., 8-12 reps, w/ 8-12 1RM load, 4 sets, 3 min rest • Both groups, ECC movement was in a slow controlled manner, 90 degrees knee flexion • Fast group CON movement explosively • Slow group CON movement slow • Measured MRFD (N/ms) & peak force from Kistler force platform ISOM	• Both groups $\uparrow$ SIG in measures of 1RM, power, hypertrophy • No SIG differences btwn the groups in gains • Fast group did $\uparrow$ MRFD to a greater extent (68.7 -23.5%) • Slow group improved strength (31-12.4%) and vertical jump height (7-4%) to a greater extent

(Table 7 Continued)

Staron et. al., 1994	• 35 healthy men & women • No previous resistance training • 13 men (~23 yrs) & 8 women (~20 yrs)	• 9 wks, 2X/wk, every other week, max on 3rd day • 2 warm-up sets • Mon, 3 sets to failure with 6-8 reps • Fri, 3 sets 10-12 reps to failure • 2 min rest btwn sets • Exercises, squat, leg press and extension	• No SIG Δ in body, lean or fat mass, or girths • 1RM leg strength relative to lean mass ↑ SIG in men lower body after 4 wks of training w/ all exercises • Women SIG ↑ 1RM in the leg press in 2 wks and squat and leg extension in 4 wks • Similar relative value ↑'s • ↑'s in cross-sectional area were non SIG • ↑ in IIa and I fibers, ↓ IIb fibers • In men ↑ SIG testosterone in 4 wk., ↓ SIG in cortisol after 6 wk • Inverse correlation with ↓ coritsol and ↑ in IIb fibers

(Table 7 continued)

Newton, Kraemer, Hakkinen, Humphries & Murphy, 1996	• 17 healthy males, • Resistance training 6 mos, bench press body weight • ~ 20 yrs	• 2 test sessions separated by 4 days of rest • 1st session tested bench press 1RM using PLYO Power System & served to familiarize • 45% of 1RM for trials • Held bar at arms length, lowered & pushed up to throw bar as high as possible • 2nd session, warmed up @ 45% on bench 2x10, 5 min upper body stretch, used throwing motion • Performed same 1RM again • 2 movements tested using 45% load for three trials @ each condition 3 min rest btwn trials • Used Kistler force plate and EMG • Sampled bar displacement, ground reaction forces, & EMG @ 876 Hz.	• ECC velocities similar, press -0.7m/s & throw -0.77 m/s • CON peak & average velocities higher for the throw (1.31 & 0.84 m/s) than the press (0.96 & .066 m/s) • Throw bar accelerated over larger portion of CON phase, peak velocity later in CON phase • Average power, force & peak power higher for throw (70, 35, & 67% difference) • After 10% of movement throwing velocity & force SIG ↑ in throw

(Table 7 Continued)

Fields, et al., 1997	• 15 CA males ~ 21 yrs • 14 AA ~ 21 yrs • Had less than yr previous weight training	• Performed 1RM & power tests on leg press & Smith BP, lift weight fast as possible • Legs warm-up w/ weight = to body weight for 10 reps & did 5 sets to reach max, w/ 2 min rest • Upper body warm-up w/ 50% body weight for 10 reps & 5 sets to reach max, w/ 2 min rest btwn • Tests repeated 2-4 days later • Power, warm-up with upper body at 50% load for 10 reps, then did 60% 1RM w/ CON movement • 3 trials w/ 1 minute rest btwn trials and 2 min rest after warm-up for power assessment • Power, lower body, perform 60% of 1RM on leg press • Piezoresistive accelerometer sampled @ 100 Hz, on bar & foot pad, collecting every 2 ms	• No SIG differences btwn. groups of age, height, weight, lean body mass, arm length or arm cross sectional area • Significant differences in body weight (AA>CA), fat weight (AA>CA), % fat (AA>CA) and thigh cross sectional area (AA>CA) • No SIG difference in strength absolute or relative or power variables upper body btwn 2 groups • Average power & power for 1st 1/3rd for lower body in AA higher (16.8 & 41%) • Difference non SIG when cross sectional area considered • Relationship strength & power differed among upper or lower muscle groups
Morrissey, et al., 1998	• 21 Women, ~24 yrs • No previous resistance training • 2 groups fast (10) and slow group (11)	• 7wks, 3xwk, 3 warm-up sets & 3 sets of 8RM • Fast group trained squats 1 s up & 1 s down • Slow group trained squats 2 s up & 2 s down • Used AMTI force platform, record ground reaction forces • Used different force platforms pre/post tests, calibrated the same? • Camera filmed at 60 frames/ s	• Fast group: long jump, higher knee peak velocity & total body vertical & absolute power, vertical jump, higher average power in ankle & hip, ↑ strength @ faster speeds on ISOK 67-82 kg, compared to 57-74 kg • Slow group: vertical jump most affected by torque in knee

(Table 7 continued)

Blackard, et al., 1999	10 males ~ 24 yrs	• Orientation session practiced exercises, measured static weight on force plate in the extended push-up position, not total body weight • Performed push-ups, bench press w/ load = push-up extended force from force platform, & w/o weight • 5 reps w/ 5 min. rest	• No differences in different exercises w/ similar loads (BP w/ load & PU) • SIG differences w/ load used (BP loaded and non-loaded)
Harris, Stone, et al., 2000	• 42 collegiate football players > 1 yr • ~ 19 yrs • Performed high volume of reps before training started • Divided into 3 groups	• Tested 1RM on ¼ squat, parallel squat & mid-thigh pull • Skill & power tests involved the countermovement vertical jump, standing long jump, stair climbing, 10 yd shuttle, & 30 m sprint • Trained 4 days/wk for 9 wks • All groups same exercises w/ the same number of reps (5) & sets (5) • Heavy group training load @ approximately 80% of 1RM • High power group trained @ 30-45% of 1RM • Combination group trained 5 weeks w/ the heavy resistance & then 4 w/ the high power intensity	• Heavy resistance group ↑ SIG in 1RM (9-34%) & stair climbing tests (6%) & SIG more high power group in ¼ squat • High power group↑ SIG in ¼ squat (15.5%), mid thigh pull (22.5%), vertical jump (2.3%), stair-climbing tests (5%) & the long jump (3%) • Combination group ↑ SIG all areas except 30 m spring & long jump, SIG greater in the squat, ¼ squat, mid thigh pull compared to high power group & SIG greater in the ¼ squat to the high force group
Jones, et al., 1999	• 40 NCAA Division IAA Football players, off-season	• Group 1, trained w/ maximal CON acceleration during resistance training • Group 2 used traditional acceleration during lifts • Each group pre/post-tested w/ medicine ball throw, 1 RM BP, & PLYO PU	• End of 14 weeks both groups ↑ SIG in all tests. • Group 1 improvement SIG to Group 2, BP & medicine ball throw • Differences did exist between groups force plate reading for PLYO PU

(Table 7 continued)

Blazevich & Jenkins, 2002	• 10 male nationally ranked college sprinters, ~ 19 yrs • Sprint training for > 5 yrs & strength and power resistance training • Running 2x/wk, no distance over 600 m • Fast group & slow group	• 4 wks. of pre-training to standardize subjects, training: squat, hip extension, leg flexion and leg extension, 3 sets of 10 reps • Pre/post – test 20 m sprint (flying start and standing start), ISOK torque of hip flexion & extension & smith machine squat press • 2 training groups w/ sprint training • 7 wk. intervention, 2x/wk both groups same upper body weight training • Fast group 30-50% 1RM, fast CON velocity & ECC phase 2x long, 4 min rest • Slower group 70-90% 1RM max effort in the concentric movement, 4 min rest, ECC/CONC phase ~ 2 s each • Each group 3-10 reps per set w/ the same exercises	• Both groups had SIG ↑ in squat strength & hip extension force • Both groups had SIG ↓ in 20 m acceleration time • No SIG differences btwn groups

Table 8. Biomechanical and Training Studies of Plyometric Exercise

There were few significant post training results for gender.			
*Table abbreviations are as follows: > = greater than. (-) = negative. 1RM = 1 repetition maximum. avg = average. BP = Bench press. btwn = between. CM = countermovement. CON = concentric. ↓ = decreased. DJ = drop jump. ECC = eccentric. ↑ = increased. IEMG = integrated electromyography. ham = hamstring. ISOM = Isometric. jr = junior. max = maximal. min = minute. PLYO = plyometric. PU = push-up. quad = quadriceps. rad = radians. RFD = rate of force development. reps = repetitions. s = second. SIG = significantly. wk(s) = week(s). yr(s) = year(s)			
Author, Year	**Participants**	**Methods**	**Results**
Hakkinen, et al., 1985	• 10 male, previous resistance training, 20-35 yrs*	• Train 3X/wk for 24 wks • Jump training included PLYO & CM • Performed additional resistance training exercises 3X/wk @ 60-80% 1RM • Measured max ISOM force & force-time variables on electromechanical dynamometer	• SIG ↑ RFD from 34, 000-42,000 N/s (24%) • Small ↑ force production 10.8% • ↑ avg IEMG time curve • ↑ Fast to slow twitch muscle fiber area ratio from 0.9-1
Bobbert, et al., 1987b	• 6 physically active males ~ 25 yrs	• Performed Drop Jumps from 20, 40, 60 cm • Filmed high speed camera @ 100 Hz • Kistler force platform took readings @ 500 Hz	• (-) work larger w/ ↑ height, 258, 358-489 J from 20, 40 & 60 J • No difference in duration downward movement • Ground reaction 1½ X force for DJ60 > DJ 40 • Knee angle DJ40 (1.76 rad) > DJ 60 (1.67 rad) for push-off • Max moment & power ankle DJ40 (406 Nm/ 2,103 W) > DJ60 (350 Nm/ 2,287 W) during push-off • Amplitude of joint reaction forces ↑ with height

(Table 8 continued)

Hewett, et al., 1996	• 11 female high school volley ball players, ~ 15 yrs • 2 yrs experience	• Tested on vertical jump & height, muscle strength • Multi-component force plate sampled volley ball jump block with 0.6096 m at 480 Hz landing on one foot on the plate @ 120 Hz. • 6 wks, 3x/wk for 2 hours • 30 s of recovery btwn each exercise • Stretch before jumping, after jump training 15 min rest, weight training • Stretched 3 sets / 30 s • Weight training 1 set of 12 reps for upper body, 15 reps for lower body and 45 reps for trunk with universal gym	• Peak landing forces ↓ from block shot by 22% • Knee abd/adduction ↓ 50% • ↑ in ham. : quad. peak torque ↑'s most in non-dominant 26% and in dominant 13% • ↑ power by 44% in the hamstring on the dominant side and 21% non dominant side
Young, et al., 1999a	• 35 males ~ 19-34 yrs, 1 yr exp activities w/ jumping • Group 1, (11) DJ for max height • Group 2, (5) DJ for max height and minimal ground contact time • Control (9)	• Tested standing & run-up vertical jump, arm swing permitted • Loaded squat jump tests • Tested squat jump relative to body weight on force platform (1000 Hz for 0.5 s) • DJ height for max height, used progressive order of 30-75 cm @ 15 cm intervals (30 s rest btwn trials) • DJ for max height w/ minimum contact time, from same 4 heights • Max strength of legs ISOM squat • Trained 3 sessions/wk for 6 wks (72-90 jumps/wk) • 4 sets of 6 jumps/session, 4-5 min rest in btwn • 1st session 4 wks • 2nd session weeks 5&6, 5 sets	• No SIG gains made by groups 1 or 2 in jumping performance • Group 2 improved reactive strength by 20% • Group 2 did ↑ in standing vertical jump, run-up vertical jump, DJ height, DJ height for minimal time • Group 1 ↑ jump force per body weight, drop jump height and drop jump height w/ minimal contact time • Improvements in both groups were non-SIG, & Group 2 improvements were larger

(Table 8 continued)

Young, et al., 1999b	• 29 males, previously involved in jumping activities, 19-34 yrs • 1 yr experience in running and jumping activities	• Performed 2 jump tests and 5 strength tests • Jumps performed w/ arm swing, standing and run-up (1,3,5&7 stride approach) vertical jump tests • Squat jumps on PLYO power system • Max dynamic strength relative to body weight (jump squat on a force platform with bar) • DJ for height (30,45,60,75 cm) • DJ for height/ w/ minimal time • Max ISOM squat tests • 3 trials for each test	• DJ tests correlated strongly w/ run-up jumps (0.7) • Standing vertical jump correlated strongly (0.8) w/ squat jump and the DJ for height
Hrysomallis & Kidgell, 2001	• 12 healthy resistance trained active males	• Group 1 performed explosive PU and then were tested on force plate while performing 3 explosive PU • Group 2 performed 5 RM BP & then 3 explosive PU	• No SIG differences btwn the groups performance on the force platform
Matavulj, et al., 2001	• 33 male jr basketball players ~ 15-16 yrs • 7 jr national team • 5-8 yrs experience • 3 groups, control, 50 cm (E50), 100 cm (E100)	• Tested vertical jump height w/ counter movement jump • Tested max force & MRFD in knees and hips ISOM, measured by strain gauge dynamometer • All groups participated in the same mid season training • Experimental groups trained after practice 3x/wk, 6 wks, 3 set of 10 reps, 3 min rest	• Both experimental groups experienced an ↑ in vertical jump E50 +4.8 cm & E100 + 5.6 cm • E100 SIG ↑ force ISOM @ hips & MRFD in the knees, E50 ↑ close to SIG

(Table 8 continued)

Knudson 2001	• 2 male & 1 female, experience upper body plyometrics & strength training	• Warm-up w/ 2 sets of 10 reps PU • 3 medicine balls of 4.1, 5.4 & 6.8 kg, lighter for female & heavier for male • 2 medicine ball dropped 15 times from 49-124 cm, randomly • 30 s rest btwn drops & 5 min rest btwn change of load • Performed drops onto platform & then w/ subjects on bench that was on force platform (600 Hz)	• Peak force correlated to distance ball was dropped • Impact force higher & longer on the force platform compared to individuals performing power drop • Power drop larger contact times than that of the force platform & force 80% lower • Forces produced by power drop under & over estimated from force plate

Table 9. Biomechanical and Training Studies Comparison of Exercise Methods

Author, Year	Participants	Methods	Results
There were few significant observational differences between genders.			
*Table abbreviations are as follows: (+) = positive. > = greater than. < = less than. Δ = change. BDJ = bounce drop jump. BP = bench press. CON = concentric only. CG = control group. CDJ = countermovement drop jump. CM = countermovement. CMJ = counter movement jump. CoG = center of gravity. dev = development. DJ = drop jump. ECC = eccentric. exp = experience. EXG = experimental group. ext = extension. ISOM = isometrically. jr = junior. max = maximum. mos = months. PE = physical education. PLYO = plyometric. PU = push-ups. Rad = radians. reps = repetitions. SIG = significantly. SJ = squat jump. VERT = vertical. VJ = vertical jump. VB = volleyball. yr(s) = year(s)			
Komi, & Bosco, 1978	• 25 women, PE*, ~ 20 yrs • 16 men, PE, ~ 24 yrs • 16 men, Natl Finnish VB team, ~ 24 yrs	• Performed SJ, CMJ & DJ (20-100 cm) • Hands on hips all techniques • Force platform record vertical Force	• SJ – least ↑ CoG • DJ – height fall ↑ so did ↑ in CoG (26-62 cm for men, 20-50 cm for women) • CoG. ↑'d from SJ, CMJ to DJ in all groups • All techniques men jumped highest 40-43 cm compared to 27 cm • Women better able to use elastic energy from prestretch in CMJ by 91% compared to men 50% • Change in (+) energy btwn DJ & SJ higher in women

(Table 9 continued)

Bobbert, Huing, et al., 1987a	• 10 male, VB players, ~ 23 yrs	• CMJ, BDJ, & CDJ (3 jumps for each type) • Order random • Hands on hips • Vertical force form Kistler force platform sampled @ 500 Hz • Filmed w/ 16 mm camera @ 100 Hz	• Duration of movement BDJ (0.13 s)<CDJ (0.19 s) <CMJ (0.55 s) • Height Jumped & vertical velocity BDJ (0.48 cm & 2.52 m/s) <CDJ (0.52 cm & 2.75 m/s)=CMJ (0.54 cm & 2.78 m/s) • Push off vertical force BDJ (4,099 N) > CDJ (2,649 N) >CMJ (2,094 N) • BDJ & CDJ joint moments max @ initial phase of push-off SIG ↑ • Power output & moment of knee & ankle SIG ↑ (DJ's>CMJ, BDJ>CDJ) • Angular velocity ↓ rapidly during push-off
Wilson, et al., 1993	• 64 males, weight training > 1 yr • 10 dropped out • 21-24 yrs • 15 in traditional • 13 in PLYO & max power output group • 14 in CG	• Familiarization session before testing & training begun • 2X/wk, 10 wk of training • 3-6 sets of 6-10 reps max effort in a squat movement • Groups, drop jumps, squat jumps 30% max & traditional squats • ↑ resistance, height, & sets throughout training • Load differed according to groups • 2 trials each test, sprint, VJ, peak power output on cycle, max ISOM squat • 3 min rest btwn each repeat trial and test	• All training conditions ↑ CMJ & SJ SIG • Power group ↑ CMJ SIG more than did traditional • PLYO group didn't ↑ SJ significantly • Weight group ↑ ISOM force SIG • PLYO & weight group ↑ RFD most but not SIG

(Table 9 continued)

Crowder, et al., 1993	• 34 college males	• Used medicine ball throw to test upper body power • Throw measured to the nearest inch • 2 groups strength train 3X/wk for 9 wks • Group 1 (17) traditional PU before strength training • Group 2 (17) PLOY PU then strength training • 1st wk started w/ 90% of max PU • Following wks added 2 PU each week (16 + PU total) • Same training, reps, sets & workout format • Reps depended on max # & started out w/ 90% max	• Significant gain in upper body power for PLYO training by 17.03 & 2.05 for traditional PU • F ratio in power of 90.24 btwn PLYO & traditional group
Newton & McEvoy, 1994	• 24 male jr dev, ~ 18 yrs • Previous extensive playing exp • Throw ball at 30 m/s • No previous weight training	• Tested max throwing velocity & BP 6 RM • 2X/wk, 8 wks & participated in regular training 2X wk • Medicine ball (3 kg) group (8) overhead throws & chest pass, 3 sets of 8 reps for 4 weeks, and 3 sets of 10 reps the last 4 wks, 6 sets a session, 3 min rest btwn sets • Weight training group (8), barbell BP and barbell pullover, 3 sets of 8-10reps 1st 4 wks, 3 sets of 6-8 reps the last 4 wks	• Weight group SIG Δ from pre – post for throwing velocity (31.7 → 33 m/s) • Both groups SIG ↑ in 6RM BP • Weight group ↑ SIG different from other groups • No SIG relationship found btwn throwing velocity and 6RM BP

(Table 9 continued)

Delecluse, et. al., 1994	• 78 male, PE students, ~ 18-22 yrs • No previous strength training program • 24 students to EXG groups and 15 students to each CG	• EXG either performed high resistance or PLYO training 2x/wk with 1X/wk for running for 9 wks • CG one ran once a week with other groups & the other group didn't • All groups tested 100m sprint speed prior to & after intervention • High resistance free & machine weights, upper & lower body training 3 sets 6-15 reps (wks 1-6) and 4 sets of 3-5 reps (wk 7-9) (instructed move as fast as possible), tested 10RM • PLYO unloaded, executed jumps quickly, 3 rotations 10 exercises per circuit, sets 3x5, 1x15, 1x5, 1x20, 4x5, tested bounding, hopping and jumping prior to	• Heavy resistance group ↑ SIG on all 10 RM tests • PLYO group ↑ SIG on all bounding, jumping, hopping and throwing tests • PLYO ↑ SIG to all groups in initial acceleration, to the non-trained CG in max speed & ↓ in speed endurance compared to CG & ↓ SIG in 100m time compared to CG • Heavy resistance group ↑ SIG in initial acceleration

(Table 9 continued)

Newton, et. al., 1997	• 17 exercise students, bench @ least own weight & been lifting previous 6 mos • ~ 20 yrs	• 2 testing sessions separated by 4 days • 1st session 1RM bench, w/ 45% of RM with throws • One type of throw was a CON throw, started 1 cm above chest and then threw for max height • Other type was a CM throw, where SSC was utilized from extended arm position to throw for max height • 2nd test session warm-up 2x10 with 45% load • Performed single SSC throw w/ 1RM • CM & CON throws tested at 15, 30,45,60,75,90% or 1RM • 3 trials for each condition, w/ 3 min rest btwn	• ↓ height of throw, velocity w/ ↑ in load • ↑ load =>↑ peak force, time of CON movement • Highest mean power output @ 30&45% • SIG difference in average velocity between CM < CON throws • Height thrown no SIG difference, CM = CON • Peak velocity signif ↑ for 75%, CM>CON • Average & peak force & power output SIG ↑ @ all loads, CM>CON • CON phase longer for CON throw • Peak velocity ↓ in ECC phase w/ heavier load • Time of ECC phase not effected by load • Avg. force ↑ w/ ↑ing load in ECC phase

(Table 9 continued)

Newton, et al., 1999	• 16 male, VB NCAA players, ~19 yrs • 2 yrs weight training & 5 yrs of VB exp • 2 groups same upper body training, leg ext./curl plus pre-season training	• Tested jump and reach, max squat 1RM, PLYO Power system jump tests at 30,60,& 90% • DJ, CMJ and SJ on force plate • CG; 3 sets each of 6 reps of leg press and squats, for 8 wks • EXG; 6 sets of ballistic squat jumps 2 sets at 30, 60, and 80% 1RM	• EXG SIG ↑ jump height standing & run-up vertical jump (6%) • EXG SIG ↑ PLYO Power squat tests all loads for bar displacement, velocity & power output • CG only ↑ those three variables @ 30% load • CM: EXG SIG ↑ force (2.1%) & power output (8%)during, CG ↑ velocity • SJ: EXG SIG ↑ peak force production all loads (5-11%) most body weight, control group ↑ peak force @ only heaviest load • Peak power output SIG ↑ (7.7%) for CG @ heaviest load • Avg power output SIG ↑ (18.9%) pre-post test for EXG @ body weight • MRFD ↑ SIG (47%) in EXG compared to the CG • DJ, EXG, SIG ↓ ground contact time (14.6%) & flight to contact ratio (24.4%)

(Table 9 continued)

Vossen, et al., 2000	• 35, healthy women, ~ 17 yrs • No current athletic activities or weight training • Group 1 CM PU • Group 2 PLYO PU	• Tested medicine ball put & 1RM chest press • 18 training sessions, 3X/wk (3sets of 10 twice, 3 sets of 11 reps, 3 sets of 12 reps, 4 sets of 10 reps, & 4 sets of 11 reps) • Group 2PLYO PU sitting upright on knees • Group 1 traditional PU w/ cadence of 2 up 2 down • 10 medicine ball puts for distance during test session with 45 s rest btwn each trial	• Group 2 ↑ (23 cm) SIG more than Group 1 (18 cm) for medicine ball put • Group 1 (4.17 kg) ↑ more than Group 2 (2.7 kg) on chest press
Cronin, et al. 2000	• 27 males, ~ 22 yrs, no previous weight training in previous 6 mos	• Tested 1RM BP, familiarized w/ CON and CM BP on modified smith machine • 2nd session warm-up, 2 sets of 10 reps @ 45% 1RM • 2nd session performed CON/CM BP • Performed each movement (twice) w/ loads of 40, 60 & 80% 1 RM load • 1 trial per movement type & load, w/ 1 min rest btwn each movement & 2 min btwn Δ of load	• CM was optimized by prior ECC (mean power output by 8-15.8%) movement more so @ the beginning of the CON phase • Stronger participants produce greater power in the initial CON phase • Performing w/ 80% max load delayed peak power in movement
Lee, et al., 2001	• 4 male & 1 female, elite swimmer	• Performed either SJ, CMJ w/ akimbo & swimming grab start • Used high speed video camera (120 Hz) synchronized to force plate (600 Hz) • Used inverse dynamics model to determine force & kinematic data	• Hip angle of grab start smaller than SJ • Center of mass for the grab start jump more forward than CM • Force, power & moment patterns differed btwn 3 jumps

(Table 9 continued)

Cronin, et al., 2002	• 27 males & 27 females, ~21 yrs • Athletic w/ no weight training w/in previous 6 mos	• Performed bench presses on modified smith press • 2 sessions, 1 to familiarize & determine 1 RM • Performed CON & rebound BP w/o release of bar • Warm-up 2nd session 2 sets 10 reps BP @ 40% max load • 2 Trials per type of movement & load w/ 1 min rest between explosive movements & 2 min btwn changing load	• Rebound motion ↑ power output • ↑ load => ↑ ECC phase, ECC acceleration & ↓ ECC velocity • CON power output best predictor for power production across gender & load • Strength best predictor power absorption for both gender & load • No SIG difference btwn gender

Consent Form:

Effect of explosive upper body exercises on biomechanical parameters in males 18-30 years of age

The purpose of this study is to identify the relationships that exist between six different upper body exercises (medicine ball throw, catch and throw, and push; and the standard push up, drop push up and pushup) and biomechanical parameters (force output, power output, and rate of force development) in males who are currently involved with resistance training. Most exercise research is conducted on the lower extremity, especially with explosive exercises which are called plyometrics.

This study will consist of three sessions lasting approximately 30 minutes. Participation will be needed for all three sessions for data collection to be complete. Participants should have no past or current upper extremity injuries, especially of the wrist, elbow, shoulder, neck, and/or back.

Data collection will include the following stages:

a. General Information: You will be given general information about this study and a chance to ask questions.
b. Measurements: All measurements will be collected in private in the Department of Kinesiology's Biomechanics Research Station in the IM Sports Circle Building on the campus of Michigan State University.
    i. Body weight will be assessed on a force plate and weight scale.
    ii. Upper body weight will be recorded in a pushup position with the shoulders directly over a force plate and in a position lying on the back with the shoulder blades on the force plate.
    iii. Standing height will be assessed with a standard stadiometer.
    iv. Right arm length will be assessed with a short anthropometer.
    v. Width of shoulders will be assessed with a bow caliper.
    vi. Upper body strength will be assessed via a ten repetition bench press after a standardized warm-up.
    vii. A digital video camera will be used to record events of the exercises (medicine ball throw and pushup).
    viii. A light weight accelerometer will be taped to the participant's back during the last two sessions.
    ix. Force and power output and the rate of force development will be measured for the performances of the 6 exercises.
c. Sports and training survey:
    i. On the survey information will be asked about age, gender, training experience and sports background.

You are asked to participate in this study because you are 18-30 years of age, healthy, and have been previously involved with resistance training. There is no economical benefit from your participation. Your participation is totally voluntary. You may choose to participate or not and discontinue your participation at any time without any explanation. By participating in this study, you agree that the materials and data generated (pictures and measurements) may be used for research and academic purposes. You have also been assured that your privacy will be protected to the maximum extent allowable by law. When this research is completed, an abstract of the results will be emailed to you. You may also seek personal data of your results to compare the exercise methods used.

(Consent Form continued)

If you are injured as a result of your participation in this research project, Michigan State University will assist you in obtaining emergency care, if necessary, for your research related injuries. If you have insurance for medical care, your insurance carrier will be billed in the ordinary manner. As with any medical insurance, any costs that are not covered or in excess of what are paid by your insurance, including deductibles, will be your responsibility. Financial compensation for lost wages, disability, pain, or discomfort is not available. This does not mean that you are giving up any legal rights you may have.

If you have any questions about this study, please contact Dr. Eugene Brown ((517)353-6491, ewbrown@msu.edu <mailto: ewbrown@msu.edu>) or Kris Kotrla ((517)267-0011, kotrlakr@msu.edu <mailto: kotrlakr@msu.edu>) at the Kinesiology Department, 204 IM Sports CIR East Lansing MI 48824-1049. 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 – Peter Vasilenko, PhD., Chair of the University Committee on Research Involving Human Subject (UCRIHS) by phone: (517)355-2180, fax: (517)432-4503, email: ucrihs@msu.edu <mailto:ucrihs@msu.edu>, or regular mail: 202 Olds Hall, East Lansing, MI 48824.

Your signature below indicates your voluntary agreement to participate in this study.

Name of participant:________________________ Signature:____________________________
Date:________ Mailing Address:____
Phone:_________________ Email address:____
Date of Birth:____________

Listserv for Recruitment:

Dear Kinesiology Students,

My name is Kris Kotrla, I am a graduate student at Michigan State University in the department of kinesiology. My master's thesis is, "Effect of explosive upper body exercises on biomechanical parameters in males 18-30 years of age". I am looking for male participants in this study.

If you are 1) currently participating in resistance training 2) 18 to 30 years of age and 3) free of injury or past injury (especially in wrist, elbow, shoulder, neck and back) then you are the person for this study.

The purpose of this study is to determine the effects of performing different upper body exercises on biomechanical variables. This study will involve 3 sessions within a weeks time. An orientation session will involve a demonstration of the exercises (medicine ball throw, catch and throw, and push; and the standard push up, drop push up and pushup), a consent form, a short survey (age, gender, training and sports background), and measurements taken of body height, length and weight. A 10 repetition maximal bench press will also be performed during this session and practice with the exercises and equipment used (force plate & accelerometer). The following sessions will involve performing the pushup and medicine ball throws in a selected order on a force platform(s). From these testing sessions information will be determined of individuals power output, force production and maximal rate of force development. Each session will take about 30 minutes. Athletic shoes, shorts/pants and shirts are required for participation. Once the study starts upper body resistance training will not be allowed for that week of participation in the study due to fatigue.

The majority of exercises in this study have minimal risks. With explosive (plyometric) exercises there is naturally more of a potential for injury. Devices, program design, and participant requirements have been set to help minimize the risk for injury. Benefits that would be received through this study are certified teaching and instruction in performing plyometric exercises which could be added to an exercise regimen. Additional benefits to participants will include biomechanical analysis of the upper body's ability to exert force and power and the maximal rate in which force is applied. This study would also contribute knowledge to an area of exercise science that has not been thoroughly investigated which would help researchers, coaches and weight trainers.

Orientation and testing sessions will be held at 107 IM Sports Cir, East Lansing MI 48824-1049. This study will run from 8/14 to 9/3/2004. The orientation sessions will be held on Saturday from 9 a.m. to 4 p.m. Testing sessions will be held the following week on a Monday and Wednesday or Tuesday and Thursday from 6 p.m. to 9 p.m.

If you are interested in participating, email me at kotrlakr@msu.edu or call me at (517) 267-0011 for questions and scheduling.

The goal is to have 30 individuals participate in this study.
Your participation in this study will definitely provide help and be greatly appreciated. If you know of others who would be qualified and willing to participate please inform them too. Thank you for taking time to read this message.

Flyer for Recruitment:

Participants Needed for Weight Training Study

Men who are **18-30 years old**, currently involved with **resistance training,** and **free of any past or current injury to the upper body** are needed for this study.

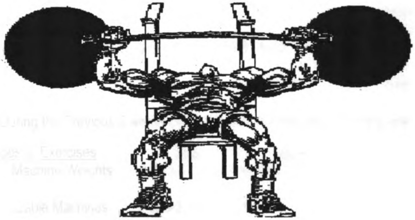
This study is set up with different upper body exercises (medicine ball throw, catch and throw, and push; and the standard push up, drop push up and pushup) to determine their effect on biomechanical variables (power output, force production, and ability to develop force at a high rate).

Three testing sessions will be performed within a week's time, each session lasting around **30 minutes**. Testing sessions will be held in the Department of Kinesiology's Biomechanics Research Station at 107 IM Sports Cir, East Lansing MI 48824-1049, on the campus of Michigan State University.

The majority of exercises in this study have minimal risks. With explosive exercises (plyometric exercises) there is naturally more of a potential for injury. Devices, program design, and participant requirements have been set to help minimize the risk for injury. Benefits that would be received through this study are certified teaching and instruction in performing plyometric exercises which could be added to an exercise regimen. There will also be an assessment of the upper body's maximal strength with the bench press. Additional benefits to participants will include biomechanical analysis of the upper body's ability to exert force and power and an assessment of maximal rate in which force is applied. This study would also contribute knowledge to an area of exercise science that has not been thoroughly investigated which would help researchers, coaches, and weight trainers

If you are interested in participating, email me at **kotrlakr@msu.edu** or call me at **(517) 267-0011** for questions and scheduling.

Thank you for taking time to read this message.



Questionnaire:

Name: ____ Date: ____________

Circle the number according to your age:

1. Under 18	8. 24-25
2. 18-19	9. 25-26
3. 19-20	10. 26-27
4. 20-21	11. 27-28
5. 21-22	12. 28-29
6. 22-23	13. 29-30
7. 23-24	14. Over 30

Circle the number for your gender:

1. Female 2. Male

Circle the number and letter of all that apply to Resistance Training Background & Participation:

Types of Exercises	Sets	Reps	Duration
1. Machine Weights	1-3, 3-5, >5	1-6, 6-12, 12-20, > 20	<2mon, 2-6 mos, 6mos-1yr, 1-3yrs, >3 yrs
2. Cable Machines	1-3, 3-5, >5	1-6, 6-12, 12-20, > 20	<2mon, 2-6 mos, 6mos-1yr, 1-3yrs, >3 yrs
3. Free Weights	1-3, 3-5, >5	1-6, 6-12, 12-20, > 20	<2mon, 2-6 mos, 6mos-1yr, 1-3yrs, >3 yrs
4. Body Weight	1-3, 3-5, >5	1-6, 6-12, 12-20, > 20	<2mon, 2-6 mos, 6mos-1yr, 1-3yrs, >3 yrs
5. Plyometrics	1-3, 3-5, >5	1-6, 6-12, 12-20, > 20	<2mon, 2-6 mos, 6mos-1yr, 1-3yrs, >3 yrs

During the Previous 6 weeks circle the type of Resistance Training that applies:

Types of Exercises	Sets	Reps
1. Machine Weights	1-3, 3-5, >5	1-6, 6-12, 12-20, > 20
2. Cable Machines	1-3, 3-5, >5	1-6, 6-12, 12-20, > 20

(Questionnaire continued)

3. Free Weights 1-3, 3-5, >5 1-6, 6-12, 12-20, > 20

4. Body Weight 1-3, 3-5, >5 1-6, 6-12, 12-20, > 20

5. Plyometrics 1-3, 3-5, >5 1-6, 6-12, 12-20, > 20

Circle the number and letter that apply to Sports Participation and Level:
(H – high school & C – collegiate level)

1. Baseball
   a. Catcher - H/C
   b. Pitcher - H/C
   c. Infield - H/C
   d. Outfield - H/C
2. Basketball - H/C
3. Cross Country - H/C
4. Football
   a. Offensive/Defensive Line - H/C
   b. Running back/ Linebacker- H/C
   c. Receiver/Defensive back - H/C
   d. Quarterback - H/C
5. Golf - H/C
6. Ice Hockey - H/C
7. Lacrosse - H/C
8. Soccer - H/C
9. Swimming
   a. Sprints - H/C
   b. Endurance - H/C
10. Tennis - H/C
11. Track & Field
    a. Throwing Events
       i. Javelin - H/C
       ii. Shot Put – H/C
       iii. Discus - H/C
    b. Running Events
       i. Sprints (400 yd or less) - H/C
       ii. Distance (800 yd or over) - H/C
    c. Jumping Events
       i. Triple Jump - H/C
       ii. High Jump - H/C
       iii. Long Jump - H/C
12. Weight Lifting - H/C
13. Wrestling- H/C

Anthropometric Recording Form:

Name:____

Date:____________

_____Height (cm)

_____Total Body Weight (lbs)

_____Weight Body Weight (kg)

_____ Push-up Weight (kg)

_____ Back Lying Weight (kg)

_____ Upper Extremity Length (cm)

_____ Biacromial Width (cm)

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