The use of a counter-balance weight system of a Smith machine affects measures of bench press throw performance. Twenty-four men performed bench press throws at 30% of their one-repetition maximum under four different conditions: 1) counter-balance and rebound movement (RC), 2) no counter-balance and rebound movement (RNC), 3) counter-balance and concentric only movement (CC), and 4) no counter-balance and concentric only movement (CNC). Peak power, force, and concentric and eccentric velocities were measured using a linear accelerometer; and peak ground reaction force (GRF) was measured using a forceplate. Peak measures for concentric and eccentric velocities showed that NCB > CB and RBT > CBT. Peak GRF measures showed CB > NCB and RBT > CBT. The lower performance measures for CB were likely due to an increase in the net external load when the barbell accelerates faster than the gravitational constant causing the counter-balance weight becomes ineffective.
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by
Harsh Buddhadev
ACKNOWLEDGEMENTS

I offer my sincere gratitude to Dr. Jakob Vingren, my major professor for his knowledge, patience, and encouragement throughout my thesis work. I also like to express my gratitude to Dr. David Hill, Dr. Simon Driver and Dr. Noreen Goggin for being a part of my committee and providing valuable input to improve the quality of my research. I would like to thank my friend, Anthony Duplanty, for assisting me during collection of the data and also all the participants who volunteered to be a part of my research study.
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CHAPTER 1
INTRODUCTION

Power assessments can be used in athletic testing and during rehabilitation to create, monitor, and modify exercise programs. Muscle power influences performance in specific movements during sport activities such as throwing, striking, and jumping. Thus, muscle power capability can be used in predicting performance in many sports activities. Upper-body muscle power capability can be assessed by performing maximal effort bench press throws (Baker, Nance, & Moore, 2001; Clark, Bryant, & Hao Pua, 2010; Cronin, McNair, & Marshall, 2001; Cronin & Henderson, 2004). However, differences in the technique used (e.g., rebound movement vs. concentric only movement) for the bench press throws affect performance measures (Clark et al., 2010). A rebound movement bench press throw produces higher power, force, and velocity during the concentric phase of the movement compared to a concentric only bench press throw (Clark et al., 2010; Cronin et al., 2001; Cronin & Henderson, 2004; Newton, Murphy, Humphries, Wilson, Kraemer, & Hakkinen, 1997).

The use of a rebound movement during a bench press throw potentiates performance due to the stretch shortening cycle (SSC), in which there is an active stretch of the working muscles (pectoralis major, anterior deltoid, and triceps brachi) during the eccentric muscle action that immediately precedes the concentric muscle action. During the stretch phase of the SSC, the eccentric muscle tension causes storage of strain energy in the muscle-tendon unit and the rapid change of muscle length stimulates the muscle spindles, causing a stretch reflex. In the concentric phase, immediately following the stretch phase, performance is enhanced due to the release of
the stored strain energy (Bosco, Komi, & Ito, 1981; Chapman, 1985; Komi, 1984; Wilson, Wood, & Elliot, 1991) and reflex potentiation that causes increased neural activity in the actively stretched muscle and, thus, increased muscle force production (Komi, 1984). The SSC for a bench press throw enhances performance only when three conditions are met: a well-timed pre-activation of the muscle prior to the eccentric phase of a bench press throw, a quick eccentric stretch, and an immediate transition between the eccentric and concentric phases (short coupling time) (Komi & Gollhoffer, 1997). Increased stretch velocity (prestretch speed) and shorter coupling time are associated with enhanced performance during the concentric phase of a SSC (Bosco et al., 1981).

Measures of bench press throw performance (power, force, and velocity of movement) can be obtained using free weight equipment but due to the increased risk of injury and the curvilinear barbell path involved in free weight bench press throws, Smith machines are commonly used when assessing bench press throw performance. Also, Smith machines allow only vertical movement of the barbell facilitating the use of linear accelerometers that measure velocity in the vertical plane only.

Smith machines often utilize a pulley system with counter-weight to reduce the net weight of the barbell. It has been shown that the use of a counter-weight significantly reduces measures of peak power, force, and velocity for the bench press throw (Vingren, Buddhadev, Evans, & Hill, 2010). The counter-balance pulley system of a Smith machine results in a uniform acceleration of the barbell and counter-weights according to the laws of uniform acceleration during the eccentric phase. The magnitude of the uniform acceleration depends upon the difference between the masses of the counter-weight and the barbell. However, regardless of the difference in
masses, the magnitude of uniform acceleration will always be less than the gravitational constant \((g = 9.82 \, \text{m} \cdot \text{s}^{-2})\). The reduced descend acceleration and, as a result, the reduced stretch velocity during the eccentric phase of the bench press throw movement could cause a less effective SSC when the bench press throw is performed using a counter-weight.

In addition to the effect on force production in the concentric phase consequent to its effect in the eccentric phase of the bench press throw, the use of a counter-weight could also directly affect the concentric phase of the bench throw movement. In a maximal effort bench press throw that is performed using a counter-balanced Smith machine, the counter-weight becomes ineffective when the barbell acceleration during the concentric phase is greater than the gravitational constant. An ineffective counter-weight will lead to an increased net barbell weight during the concentric phase which could affect performance measures.

To my knowledge, only one study has examined the effect of using a counter-weight on performance measures of a rebound bench press throw (Vingren et al., 2010). Vingren and colleagues found that use of a counter-weight reduced rebound bench press throw performance measures (peak power, peak force, and peak velocity of movement) calculated using measures obtained using a linear accelerometer. However, the study did not investigate the physiological and biomechanical causes for this reduction in performance measures. In addition, No study has investigated the effect of using a counter-weight on performance measures of power, force, and velocity in) concentric only bench press throws. The use of a counter-weight could reduce the stretch velocity during the eccentric phase, consequently affecting the SSC. In addition,
during the concentric phase the counter-weight could become ineffective resulting in an increased net weight of the barbell. Therefore, the purpose of this study was to determine the underlying physiological and biomechanical causes of reduced power, force, and velocity associated with the use of a counter-weight. This was done by investigating the effect of using a counter-weight system on muscle activation and performance measures for rebound and concentric only movement bench press throws.
CHAPTER 2
REVIEW OF LITERATURE

This literature review examines power assessment, the stretch shortening cycle, and laws of uniform acceleration affecting a pulley system, as well as the variables affecting them. Additionally this review examines how the use of a counter-balanced Smith machine affects performance variables during maximal power assessment while performing rebound and concentric only bench press throws.

Power Assessment

Mechanical variables, such as power, force, rate of force development, velocity of movement, and impulse, influence the performance in specific movements such as throwing, striking, and jumping during sport activities. Power is one of the main factors that determine performance in sports activities. As a result power assessments are common in research, athletics, and rehabilitation settings to monitor training or rehabilitation progression and to modify exercise prescription.

Power is a scalar quantity, defined as the rate of performing mechanical work or as the product of the force applied and the velocity of the movement. Explosive muscle power refers to high levels of power output during a single, maximum effort muscle action (Newton & Kraemer, 1994). High power output is needed in sports and athletic events where an athlete needs to change direction or accelerate rapidly, such as football, basketball, baseball, soccer and gymnastics. Muscle properties that are crucial for explosive power performance are strength, rate of force development and the ability to continue producing high forces as the velocity of muscle shortening increases.
Strength is the ability of a muscle or a muscle group to generate force or torque at a specific velocity (Knutgen & Kraemer, 1987). The relationship between maximal force and velocity of movement differs between concentric and eccentric muscle actions (Hill, 1938). During a concentric action of an isolated muscle, the ability of the muscle to generate force is less at higher shortening velocities. In contrast, for eccentric actions, the ability of the muscle to generate force is higher at higher shortening velocities (Figure 1). According to this relationship, the external resistance is the primary determinant of the force produced and maximal velocity for a movement. The force exerted during a movement increases with the external resistance and the maximal velocity of the movement decreases with increasing external resistance for concentric muscle actions (Cronin & Henderson, 2004; Newton & Kraemer, 1994). Since power is the product of force and velocity, maximum power is, therefore, achieved at less than maximal levels of force and at approximately 30% of the maximum shortening velocity (Figure 2) (Bevan, Bunce, & Owen, 2010; Newton et al., 1997; Thomas, Kraemer, & Spiering, 2007).

*Figure 1. Rate of change in muscle length adapted from Bloomfield, Fricker, & Fitch, 1992.*
Figure 2. Force-velocity relationship adapted from Faulkner, Claflin, & McCully, 1986.

In sports contexts, power assessments are used to identify talent in regard to the ability of the athlete to excel in a particular sport or to estimate relative significance of strength and power in particular athletic events. In rehabilitation programs, power assessments are used to determine the status of injury, monitor progress, and modify the program. To accurately measure power in human movements, a combination of kinematic and kinetic data and relevant biomechanical modeling are necessary (Cormie, McBride, & McCaulley, 2007; Knudson, 2009). Measurements from force platforms and kinetic sensors can be used in the calculation of external power (Garhammer, 1993; Knudson, 2009). The power reported can either be instantaneous power, often a peak value, or average power over a specified period of time. Recent studies have reported significant differences in calculated values for power that are obtained using different methodologies (Cormie et al., 2007; Dugan, Doyle, Humphries, Hasson, & Newton, 2004). Hence, it is necessary to mention specific qualifiers, the values generated (internal or external power, average or peak power, movement phase during which the
power was measured), and measurement details (model, instruments, calculations) for the power assessment (Knudson, 2009). Power assessment is also influenced by various other factors including primary type of muscle action in the event (concentric, eccentric, and isometric), coordination or skill, neuromuscular activation, and other motor performance parameters (Abernethy, Wilson, & Logan, 1995).

Power assessment can be performed using field or laboratory tests. Based on the principle of specificity, the forms of power testing and training should be similar if the purpose is to assess change and progress in an athlete’s power capability. In the past, dynamometry involving isokinetic and isoinertial modes was frequently utilized for laboratory tests. Isokinetic testing had high internal and low external validity whereas the converse was true for isoinertial dynamometry (Abernethy et al., 1995). The most widely used exercises for assessing strength and power for the upper-body is bench press, bench press throws, medicine ball throws, and seated shot put. Compared to explosive bench presses, explosive bench press throws result in a higher average and peak velocities and power, average power, and higher electromyography (EMG) outputs in the involved muscles, owing to the resistance being accelerated throughout the full range of motion (Newton, Kraemer, Hakkinen, & Humphries, 1996). During an explosive bench press, there is a deceleration phase in the latter part of the movement before the barbell comes to a stop. The time period of the deceleration phase is directly related to the relative resistance encountered in the movement. For example, the deceleration phase is proportional to 52% of the concentric movement for 81% of maximum bench press load and proportional to 40% of the concentric movement for 45% of maximum bench press load (Elliott, Wilson, & Kerr, 1989; Newton et al., 1996).
Bench press throws can be performed with a rebound movement or concentrically only movement, where the eccentric phase in absent. Rebound bench press throw resulted in significantly higher velocity, force, power and EMG activity than concentric only movements (Clark et al., 2010; Cronin et al., 2001; Cronin & Henderson, 2004; Newton et al., 1997 ;) owing to the contribution from the SSC operating during the rebound bench press throw movement.

**Stretch Shortening Cycle**

During the stretch phase of eccentric contraction of a SSC there is a strain on the muscle-tendon unit and the strain energy is stored in the series elastic component (SEC) of the muscle-tendon unit. This strain energy is released in the concentric phase augmenting the initial concentric force production by the muscle. However, the performance enhancement due to release of strain energy dissipates after 250 milliseconds of concentric action (Chapman et al., 1985; Wilson et al., 1991). Stretch due to rapid eccentric action causes stimulation of the muscle spindles, producing increased neural activity to the stretched muscle. This reflex potentiation increases the muscle's stiffness, leading to a more effective transmission of the strain energy during the initial part of the concentric phase (Bosco et al., 1981; Komi, 1984). The stretch reflex plays an important role in enhancement of performance during a SSC provided three conditions are met: 1) well timed preactivation of muscle, 2) short and fast eccentric stretch and 3) an immediate transition between stretch and shortening (Komi & Gollhoffer, 1997). The fast eccentric stretch velocity effectively stimulates the muscle spindles in the muscle. The eccentric phase also gives muscle time to develop
maximum tension which facilitates subsequent concentric action (Van Ingen, Bobbert, & Haan, 1997). Alteration of properties of the contractile machinery of the muscle during the eccentric phase has been proposed as one cause of the enhancement in performance in the concentric phase. During the eccentric stretch the myosin heads are rotated backwards to a position of higher potential energy during cross bridge attachment in the concentric phase (Huxley & Simmons, 1971).

The factors that affect a SSC by influencing the utilization of stored elastic or strain energy are the coupling time (time between the concentric and eccentric phase), stretch velocity, the final length of the muscle, force at the end of the stretch, muscle stiffness (Bosco et al., 1981; Cavagna, 1977; Morgan & Proske 1997), amount of preload (Cronin, et al., 2001) and pre-stretch (Bosco & Komi, 1979) on the muscle, and training status. Fast stretch of an active muscle causes significant reflex potentiation in Ia afferent nerve fibers from the muscle spindles which respond to a stretch beyond the current sensitivity of the muscle. Increased preload during the eccentric phase will result in an increased work produced in subsequent concentric action (Cronin et al., 2001).

The EMG activity observed during the eccentric phase of a SSC occurs due to controlled release of high energy by the eccentric muscle action which gets stored as strain energy in the muscle-tendon complex. During the concentric phase this strain energy is released leading to performance potentiation. The stretch reflex improves performance by enhancing the force production during the transition phase (stretch-shortening) in a SSC. The performance improvement depends on the amplitude of stretch reflex, which is influenced by stretch load and level of fatigue. Reflex contribution is due to regulation of muscle stiffness, which contributes during the eccentric part of a
SSC. For activation of the stretch reflex rapid transition from stretch to shortening phases and high stretch velocity are critical. Performance is potentiated during a rebound movement based on the amount of pre-stretch on the muscle (Bosco & Komi, 1979) and training status. If the pre-stretch force is higher than the muscular threshold then the protective Golgi tendon organ (GTO) reflex will inhibit the muscular contraction. The protective GTO reflex operates in response to sudden intense stretch forces to reduce the tension of the tendomuscular unit during force peak of the SSC (Golhoffer, Komi, Fujitsuka, & Miyashita, 1987). Disinhibition, or reduction in inhibition, occurs after a period of plyometric training, leading to SSC performance improvement. During explosive movements, the participants unfamiliar with the test movement may exhibit lower performance measures due to the protective Golgi tendon organ reflex compared to participants familiar with the test movement.

Laws of Uniform Acceleration (Atwood’s Machine)

George Atwood invented a device referred to as the “Atwood’s machine,” as a laboratory experiment to verify mechanical laws of uniform acceleration. He published his findings on this device in *A Treatise on the Rectilinear Motion and Rotation of Bodies, with a description of original experiment relative to the subject* (Atwood, 1784).

The ideal Atwood’s machine (Figure 3) consists of a massless frictionless pulley with a massless inelastic string passed over it. On either end of the string masses (M and m) are attached. When the masses are equal there is a static equilibrium experienced by them, irrespective of their position. When the masses (M and m) not
equal, there is uniform acceleration experienced by both these masses is lesser than the acceleration of gravity.

![Image](image.jpg)

**Figure 3.** Smith machine's counter-balance pulley system as an application of Atwood's machine.

If $T$ is the tension in the string and $g$ is the acceleration of gravity, then the net forces experienced by masses "$M$" (the heavier object) and "$m$" (the lighter object) are:

$$Ma = Mg - T \quad (1) \text{ and}$$

$$ma = T - mg \quad (2),$$

respectively, where "$a$" is the net acceleration.

Adding equations (1) and (2) one can calculate "$a$", the net acceleration:

$$a = g \frac{M - m}{M + m} \quad (3)$$
To calculate the tension (T) in the string, one must substitute value of “a” from equation (3) into (1) to get:

\[ T = g \frac{(2Mm)}{(M+m)} \]  

(4).

A Smith machine’s counter-balance system is based on the Atwood’s machine design. In a Smith machine counter-weights are used to reduce the net weight of the barbell. Since the counter-balance system uses the same principles of uniform acceleration as the Atwood’s machine, the uniform acceleration experienced by the counter-balance mass and the barbell will be less than the acceleration of gravity. A reduction in the downward acceleration causes the barbell to descend at a lower velocity than it would without the counter-weights. This slower descent of the barbell might affect a rebound bench press throw, because the slower descent reduces the stretch velocity causing the muscles to stretch at a relatively slower rate and this should lead to a less effective SSC). This less effective SSC will likely result in reduced performance measures for rebound bench press throws with counter-weights. The use of a counter-balance system results in a uniform acceleration of the barbell carriage and counter-weights that is less than the gravitational constant (g); the magnitude of this reduction in acceleration depends upon the difference between the masses of the counter-weight and barbell. In a maximal effort bench press throw using a counter-balanced Smith machine, the counter-weight will become ineffective if the upward force exerted during the concentric phase causes barbell acceleration that is greater than the gravitational constant (g). This ineffective counter-weight will result in a greater net external resistance and thus a greater force requirement during the concentric phase compared to the resistance experienced and force required for bench
press throw on a Smith machine without counter-weight. Since the external resistance dictates the maximal velocity of movement, the increased external resistance might affect performance measures.
CHAPTER 3

METHODS

Overview of the Study

This study used a $2 \times 2$ (Counter-balance × Movement type) repeated measures design with the order of conditions assigned using blocked randomization to minimize possible confounding effects of order. Participants completed two sets of bench press throws under four different conditions 1) counter-balance and rebound movement (RC), 2) no counter-balance and rebound movement (RNC), 3) counter-balance and concentric only movement (CC), and 4) no counter-balance and concentric only movement (CNC). All bench press and bench press throw exercises were performed using a Smith machine that allowed for only vertical barbell movement. For the counter-balance condition, a mass equal to that of the counter-weight (13.6 kg) was added to the barbell. Each set consisted of two repetitions of maximal effort bench press throws at 30% of bench press one-repetition maximum (1-RM) with a 5 minute rest interval between sets and exercise conditions. For each throw muscle activation and performance measures (peak power, peak force, and peak velocity of movement) were assessed.

Participants

Twenty-four apparently healthy men (mean ± standard deviation: 23 ± 3 yrs, 91.0 ± 16.9 kg, 178.9 ± 5.9 cm) were recruited for this study. All participants were informed of the risks and benefits of participation in the study and subsequently provided written informed consent (see Appendix A). The study was approved by University of North
Texas Institutional Review Board. Participants completed medical health (See Appendix B) questionnaire to help screen for pre-existing medical conditions that may have put them at risk during the exercise protocol or affect the outcomes of this study. Exclusion criteria included any limitations that would prevent completion of a bench press with full range of motion. To be included in the study each participant's 1-RM for the bench press had to be a minimum of 80.6 kg; this ensured that their 30% of 1-RM is at least 24.3 kg (the mass of the barbell alone). For the study 30% of 1-RM was used because mechanical power output peaks around that load (Bevan et al., 2010; Newton et al., 1997; Thomas et al., 2007). The bench press 1-RM for the participants was 106.9 ± 18.3 kg.

Testing Procedure

Each participant completed two experimental sessions: a 1-RM and familiarization session and a bench press throw test session; sessions were separated by 4-7 days. Each session for a particular participant was conducted at the same time of day. Participants refrained from upper-body exercise for 48 hours before the 1-RM and familiarization session and from eating for two hours before each session.

Anthropometric Measurements and One-Repetition Maximum

This session began with anthropometric measurements (height and weight) followed by a standardized upper-body warm-up consisting of shoulder range of motion and mobilization exercises including gleno-humeral and shoulder girdle rotation movements performed in clockwise and counter clockwise direction. Then the
participant’s rebound bench press 1-RM was determined (Kraemer & Fry, 1995). Briefly, the participant lowered the barbell to the chest but was not allowed to “bounce” the barbell off the chest. Participants were required to press the barbell to full elbow extension to record a successful lift. During the 1-RM assessment, muscle activation was measured from the working muscles (pectoralis major, anterior deltoid, and long head of triceps) on the right side to get peak EMG values that can later be used to normalize the peak values for the bench press throws.

_Bench Press Throws Familiarization_

After 1-RM testing, the participants performed two sets of two repetitions of rebound and two sets of concentric only bench press throws to familiarize them with the test movements. The two different bench press throw techniques were selected because they have the same movement pattern for the concentric phase but differed based on the presence and absence of an eccentric phase. A rebound bench press throw (RBT) consists of an eccentric and concentric phase, which allows operation of a SSC, whereas a concentric only bench press throw (CBT) has only a concentric phase, which does not allow for the operation of a SSC. All throws were performed with a load equal to 30% of their bench press 1-RM. All bench press exercises were completed while participants were lying supine on the bench with both feet in contact with the ground; proper alignment ensured that arms were extended over the shoulders. The participants were strapped to the bench across the upper chest to prevent body movement away from the bench (Cronin et al., 2001) and were instructed to move the barbell as fast as possible during the concentric phase of both movement types.
Participants were instructed to grip the barbell with hands shoulder width apart; the grip-width was standardized so it was the same for every throw for a particular participant. For each throw the barbell was caught by the research personnel and then immediately returned to the participant with his elbow extended for RBT and at the level of chest for CBT. A 5-minute rest period separated each set. For the rebound bench press throw, the participants were instructed to begin the movement with the arms fully extended and then lower the barbell rapidly (without pulling it down) during the eccentric phase to just above (at a distance approximately 5 cm) their mid-chest and then immediately push (throw) the barbell upward as fast as possible for the concentric phase. No pause was allowed between the eccentric and concentric phases of the movement and the barbell was not allowed to touch the chest or the safety stops on the Smith machine. For the CBT, the movement started with the barbell resting on supports ~5 cm above the participant’s chest. Participants were instructed to push (throw) the barbell upwards as fast as possible from the resting position; this procedure prevents the involvement of the SSC during the concentric only movement. After the familiarization visit, the participants were instructed to not perform any upper-body exercise for four days prior to the next testing session to allow them adequate time to recover.

*Bench Press Throws Testing*

The second session began with the standard warm-up performed for the familiarization visit followed by exercise performance testing in which the participants completed two sets of two bench press throws each at 30% of 1-RM under the four different conditions. For each throw performance variables for the barbell movement
(power, force, and velocity, ground reaction force, and muscle activation) were measured. Barbell movement power, force, and velocity were measured using a Myotest accelerometer and associated software (Myotest accelerometer, Acceltec SA, Sion, Switzerland). The ground reaction force was measured using a forceplate with associated software (Advanced Mechanical Technology Inc., Accupower, Watertown, Massachusetts) and muscle activation for the pectoralis major, the anterior deltoid, and the triceps brachii muscles on the right side of the body was measured via EMG using a MP100 System (Biopac Systems, Inc. Santa Barbara, CA, USA).

After the bench press throw testing the participants were given a 10 minute rest followed by rebound bench press 1-RM assessment. During the 1-RM assessment muscle activation was measured from the working muscles to get peak EMG values that can later be used to normalize the peak values for the bench press throws.

**Equipment**

*Smith Machine*

The Smith machine (New York Barbells, Elmira, NY) consisted of a barbell fixed to vertical steel shafts on either side of a frame. Linear bearings attached to either end of the barbell allowed it to slide up and down the two steel shafts on either side with minimum friction. It also had safety stops and a counter-balance pulley system. The counter-balance system of a Smith machine consists of counter-weights that are attached to the barbell via wires passing over the pulley systems on either sides of the equipment. Counter-weights serve the purpose of reducing the net weight of the barbell allowing users of all levels of strength to exercise. Counter-weights are sometimes
referred as “take-off” weights as they can be disconnected from the barbell carriage by unhooking the wire that connects them. The counter-weights and the barbell carriage are positioned on the either side of the pulley system and thereby exhibit reciprocal movements with respect to each other. The magnitude of the movement of the barbell carriage is equal to the movement of the counter-weight but in opposite directions. The counter-weights slid up and down the two steel shafts with minimal friction because of the linear bearings attached to the either ends. The friction during the up and down sliding movement of the counter-weights can affect the outcomes of the study. Therefore, the equipment used in the study was modified (Figure 4) to eliminate the friction by using weights equal to the mass of manufacturer provided counter-weights on either side.

Figure 4. Modified Smith machine.
**Linear Accelerometer**

The Myotest accelerometer was attached to the barbell during the bench press throws and measured peak values for barbell power, force, and velocity during eccentric and concentric phases of the movement. Measures during the eccentric phase were obtained only for the rebound throws. The Myotest accelerometer has been validated for use in bench press throw performance testing (Kraemer, 2010). The linear accelerometer measures peak acceleration and the duration of the movement. Based on the measured values of peak acceleration it calculates the peak velocity of the movement. The peak force exerted during the movement is calculated as a product of manually entered external resistance (mass) and measured peak acceleration. Finally peak power is calculated as a product of force and velocity.

**Forceplate**

A portable forceplate with associated software (Accupower, Advanced Mechanical Technology Inc., Watertown, MA) was used to measure ground reaction force for the bench press throw movements. The forceplate was placed under a wooden platform on which the bench was located. The bench was modified by removing the cushion board to maximize the transfer of forces from the participant to the forceplate (Clark et al., 2010). The modified bench was placed within the Smith machine.
Electromyography

Before the bench press throws were performed, the sites of electrode application were shaved, cleaned with alcohol and gently abraded. A small amount of conductive gel was applied to the surface electrodes before application to the skin. The electrodes were placed on the sternal portion of the pectoralis major, the anterior deltoid, and the long head of triceps muscles on the participant’s right side (Krol, Sobata, & Nawrat, 2007; Newton et al., 1997). Preamplifiers were incorporated into the electrodes with the electromyographic signal being amplified using an amplifier with low pass filtered at 500 hertz and high pass filtered 10 hertz. An MP100 System (Biopac Systems, Inc. Santa Barbara, CA, USA) was used to record EMG. A sampling frequency of 876 Hz was used for each channel for raw data acquisition. Raw data were then stored on a personal...
computer for signal processing and analysis. The raw signal was smoothed and rectified using Acknowledge 3.72 software (Biopac Systems, Inc). The peak amplitude of the EMG signal during the concentric phase was used for analysis. The peak amplitude of the EMG value for each throw was normalized relative to the peak EMG value recorded during the 1-RM trial that followed the bench press throw testing.

Statistical Analysis

The repetition with the greatest peak power for each condition was used for statistical analysis. Peak power, peak force, peak concentric velocity, peak ground reaction force, and peak amplitude of the EMG values were analyzed using two-way analysis of variances (ANOVAs) (Counter-balance × Movement type) with repeated measures on both factors. Fisher’s LSD post-hoc was used to determine pair-wise differences when significant interaction effects were found using the ANOVA. A paired t-test was used to compare peak velocity from the eccentric phase of the rebound throws performed with and without a counter-weight. The alpha level for significance was set at \( p < 0.05 \). Data are presented as mean ± standard error unless otherwise indicated.
CHAPTER 4

RESULTS

Peak Power

For peak power (Figure 6) there were significant ($p < 0.05$) main effects for counter-balance condition ($F = 37.11$, $df = 23$, partial $\eta^2 = 0.617$) and movement type ($F = 18.63$, $df = 23$, partial $\eta^2 = 0.448$), and there was an interaction effect (counter-balance $\times$ movement type) ($F = 4.87$, $df = 23$, partial $\eta^2 = 0.175$). Peak power was greater for no counter-balance compared to counter-balance and for rebound compared to concentric only movement. Pair-wise comparisons revealed that peak power was higher for RNC compared to RC condition. There was a trend ($p = 0.097$) for the peak power for RNC being greater than for CNC. Peak power for CNC and RC was greater than for CC.

Figure 6. Peak power, RNC= rebound no counter-balance, RC=rebound counter-balance, CNC=concentric only no counter-balance, CC=concentric only counter-balance. * Significantly ($p < 0.05$) different from CC, ^ significantly ($p < 0.05$) different from RC. Mean ± SE.
Peak Force

For peak force measured with the accelerometer (Figure 7) there were main effects for counter-balance condition \(F = 122.55, df = 23, \text{ partial } \eta^2 = 0.842\) and movement type \(F = 61.77, df = 23, \text{ partial } \eta^2 = 0.729\), and there was an interaction effect (counter-balance × movement type) \(F = 4.87, df = 23, \text{ partial } \eta^2 = 0.175\). Peak force was greater for RNC than for RC, and CNC. The RC and CNC conditions had greater peak force compared to the CC condition.

For the peak ground-reaction force measured with the forceplate (Figure 8) there were main effects for counter-balance condition \(F = 4.45, df = 23, \text{ partial } \eta^2 = 0.162\) and movement type \(F = 34.88, df = 23, \text{ partial } \eta^2 = 0.603\), but there was no interaction effect. The peak ground reaction force was smaller for the no counter-balance compared to the counter-balanced condition and greater for rebound compared to concentric only movement.

![Figure 7. Peak force, RNC= Rebound no counter-balance, RC=Rebound counter-balance, CNC=Concentric only no counter-balance, CC=Concentric only counter-balance. * Significantly different \((p < 0.05)\) from CC, # significantly \((p < 0.05)\) different from CNC, ^ significantly \((p < 0.05)\) different from RC. Mean ± SE.](image-url)
Figure 8. Peak ground reaction force, RNC= Rebound no counter-balance, RC=Rebound counter-balance, CNC=Concentric only no Counter-balance, CC=Concentric only counter-balance. $ Significant (p < 0.05) main effect of movement type, % significant (p < 0.05) main effect of counter-balance. Mean ± SE.

Peak Velocity of Eccentric and Concentric Phases

The peak eccentric velocity (Figure 9) was greater ($ t = 3.04, df = 23, r = 0.511$) for RNC than for RC. For the peak concentric velocity (Figure 10) there were main effects for counter-balance condition ($ F = 26.88, df = 23, partial \eta^2 = 0.539$) and movement type ($ F = 8.56, df = 23, partial \eta^2 = 0.271$), and there was no interaction effect. The peak concentric velocity was greater for no counter-balance compared to counter-balance and for rebound compared to concentric only movement.
Figure 9: Peak Eccentric Velocity, RNC= Rebound No Counterbalance, RC=Rebound Counterbalance, CNC=Concentric Only N0 Counterbalance, CC=Concentric Only Counterbalance. ^ Significantly ($p < 0.05$) different from RC. Mean ± SE.

Figure 10: Peak Concentric Velocity, RNC= Rebound No Counter-balance, RC=Rebound Counter-balance, CNC=Concentric Only N0 Counter-balance, CC=Concentric Only Counter-balance. $ $ Significant ($p < 0.05$) main effect of movement type, % significant ($p < 0.05$) main effect of counter-balance. Mean ± SE.
Peak EMG

There was no main effect of counter-balance on peak pectoral, deltoid, or triceps EMG values (Table 1). The movement type did not affect peak pectoral or triceps EMG values. For peak deltoid EMG values there was a main effect for movement type ($F = 11.18$, $df = 23$, partial $\eta^2 = 0.327$); values were greater for rebound compared to concentric only movement. There was an interaction effect for peak pectoral EMG values ($F = 12.44$, $df = 23$, partial $\eta^2 = 0.351$); the values were smaller for RNC compared to RC and CNC and greater for RC compared to CC. There was a trend ($p = 0.088$) for peak pectoral EMG values for CNC being greater than for CC.

Table 1

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Pectoral</th>
<th>Deltoid</th>
<th>Triceps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rebound No Counter-balance</td>
<td>91.0 ± 4.4 ($^#$)</td>
<td>97.4 ± 6.6 ($)</td>
<td>85.5 ± 7.8</td>
</tr>
<tr>
<td>Rebound Counter-balance</td>
<td>101.5 ± 4.8 (*)</td>
<td>98.3 ± 4.8 ($)</td>
<td>84.8 ± 5.6</td>
</tr>
<tr>
<td>Concentric only No Counter-balance</td>
<td>98.0 ± 6.0</td>
<td>87.1 ± 5.0</td>
<td>84.5 ± 5.0</td>
</tr>
<tr>
<td>Concentric only Counter-balance</td>
<td>92.2 ± 4.9</td>
<td>89.0 ± 5.3</td>
<td>82.8 ± 4.8</td>
</tr>
</tbody>
</table>

$ $ Significant ($p < 0.05$) main effect of movement, $^*$ significantly different ($p < 0.05$) from CC, $#$ significantly ($p < 0.05$) different from CNC, $^\wedge$ significantly ($p < 0.05$) different from RC. Mean ± SE.
CHAPTER 5
DISCUSSION

The present study confirmed the findings of Vingren et al. (2010) that the use of a counter-weight resulted in lower accelerometer based measures for barbell peak power, peak force, and peak concentric velocity in a rebound bench press throw. The primary finding of this study was that these reductions appeared to be due to reduced stretch velocity during the eccentric phase and increased external resistance (net weight) during the concentric phase.

During the concentric phase of the bench press throw performed using a counter-balance system, there was an increase in the peak ground reaction force measured from forceplate but a decrease in the peak barbell force calculated using the linear accelerometer. During explosive movements, such as the concentric phase of bench press throws, when the upward acceleration of the bar exceeds the downward acceleration of the counter-weight due to gravity, the wire connecting the counter-weight and the barbell becomes slack and thus the counter-balance system no longer reduces the resultant weight of the barbell. The increase in the peak ground reaction force with the counter-balance system found in the present study was independent of movement type implying that the external resistance (net weight) increased during the concentric phase and as a result the participants exerted a greater force. This finding is supported by previous studies reporting that peak ground reaction force increased with increasing external resistance (Cronin & Henderson, 2004; Newton et al., 1997). The increased external resistance likely reduced the concentric phase barbell acceleration since heavier loads cannot be accelerated as rapidly as lighter loads (Newton et al., 1997).
The linear accelerometer calculated the peak force exerted during the counter-balance condition on the basis of this reduced barbell acceleration and the initial (manually entered) external resistance, hence providing a reduced peak force measures for the counter-balance condition. The counter-balance system induced reduction in accelerometer based measures of peak concentric force. This reduction was greater for the rebound compared to the concentric only movement type, thus the use of a counter-balance system appears to also affect aspects of the eccentric phase that influence maximal force production.

During the eccentric phase the peak velocity was higher for RNC compared to RC. This slower eccentric velocity for RC can be explained by the laws of uniform acceleration (Atwood, 1784); the use of a counter-balance pulley system on a Smith machine results in a uniform acceleration of the barbell carriage and counter-weights during the eccentric phase. The magnitude of this acceleration will always be less than the gravitational constant \( g = 9.82 \text{ m} \cdot \text{s}^{-2} \) and will therefore result in a slower peak eccentric velocity for RC compared to RNC. The peak eccentric velocity is considered the peak stretch velocity (Cronin et al., 2001) and reductions in peak stretch velocity of the SSC reduces performance measures during the concentric phase of the movement (Bosco et al., 1981). In the present study the peak eccentric velocity was slightly reduced (~5%) but this reduction did not appear to be sufficient to affect the SSC since only main effects were found for peak concentric velocity and ground reaction force (these measures are not directly affected by the manual input of load values into the accelerometer). Peak concentric velocity was reduced for the counter-balanced condition and for the concentric only condition. The reduction in peak concentric velocity
was likely due to the increase in the external resistance during the explosive movements. Previous studies have reported that peak concentric velocities are reduced with increasing workload (Cronin & Henderson, 2004; Hill, 1938; Newton et al., 1997).

Similar to findings of Vingren et al. (2010) the accelerometer based measures of peak power were reduced both types of bench press throws while using the counter-balanced system. Power is function of force and velocity and thus the reduction in accelerometer based measure of peak power can be explained by reductions in the peak force and peak velocity. An increase in the external resistance during the concentric phase helps explain the findings of the current study. The findings of the current study are in agreement with findings of other studies (Bevan et al., 2010; Cronin & Henderson, 2004; Newton et al., 1997; Thomas et al., 2007) that reported that peak power reduced with increasing workload.

The peak EMG activity of the pectoral muscles increased during RC compared to RNC possibly due to increase in external resistance during the concentric phase for the counter-balance condition. But no increase in peak pectoral EMG was found for CC compared to CNC. The findings of the current study were partially in agreement Newton et al. (1997) who reported that the peak pectoral EMG activity increased with increasing workload for both movement types. The use of a counter-balance system did not affect the peak deltoid EMG activity because peak deltoid is not affected by increasing external resistance (Newton et al., 1997). In the current study, the peak EMG activity of triceps was not affected by increasing external load due to counter-balance condition but in Newton et al. (1997) study reported that peak triceps activity increased with increasing external resistance.
The effect of movement type (rebound versus concentric only) for the bench press throw performance measures such as peak power, peak force, peak concentric and eccentric (stretch) velocities, and EMG have been investigated extensively (Bevan et al., 2010; Clark et al., 2010; Cronin et al., 2001; Cronin & Henderson, 2004; Newton et al., 1997; Thomas et al., 2007). In agreement with previous investigations (Clark et al., 2010; Cronin et al., 2001; Cronin & Henderson, 2004; Newton et al., 1997), the present study found that peak power and peak force were higher for the rebound movement compared to the concentric only movement. The peak concentric velocity for the present study was also higher for the rebound compared to the concentric only movement; this is in contrast to the findings of Newton et al. (1997) who did not find differences in the peak concentric velocity between movement types for bench press throws. The current findings for the effect of movement type on EMG is also partially in contrast to the findings of Newton et al. (1997) who found that peak EMG values for pectoral, deltoid and triceps muscles did not differ based on movement type. In the current study the peak deltoid EMG value was greater for the rebound movement compared to the concentric only movement. Peak pectoral activity was lesser for the RNC compared to CNC. The peak pectoral EMG values were greater for RC compared to CC because the pectoral muscle activity peaks during the later part of the throw when the bar is actually thrown (Newton, 1996).

There are two primary limitations for this study, both related to EMG measurements. 1) Participants performed the 1-RM 30 minutes after performing the bench press throw testing which might have caused some fatigue and thus lower EMG values for normalization. Since the 1-RM EMG was only used to normalize the bench
press throw EMGs, a lower 1-RM EMG might have inflated the relative values for bench press throw EMG but would not affect the outcome of the EMG analysis. 2) During testing movement artifacts (EMG electrodes or wires being pulled causing a signal spike) occasionally occurred while recording EMG data. During the testing procedure all the wires connecting EMG electrodes had enough of slack and all the electrode were secured to the skin with an additional athletic tape so they would not pull during the throw, but these attempts were not enough to completely prevent movement artifacts. The presence of movement artifacts sometimes made it difficult to isolate the peak EMG value for a throw.

The practical implication of this study is that the use of a counter-balance system should be avoided during testing of explosive movements. Individuals with lower strength abilities exercising on a Smith machine at lower pace may benefit from using the counterbalance system, as the system reduces the net weight of the barbell, thus allowing users with lower strength levels to work out with a Smith machine barbell which is relatively heavy.

The current study investigated how the use of a counter-balance Smith machine affected measures of bench press throws in young men who were able to bench press a minimum of 80.6 kg. Future studies should investigate how the use of a counter-balance Smith machine affects measures of performance in different test movements (e.g. jump-squats, high-pulls, etc.) and different populations (e.g., women, highly trained power athletes etc.).

In conclusion, use of the counterbalance system causes an under-estimation of measures of power, force and velocity capability that are based on measures obtained
using the accelerometer and an increase in the actual force output (ground reaction force). The increasing external resistance (load) during the concentric phase was likely responsible for the reductions in the accelerometer based performance measures observed for bench press throws using the counter-balance system. Based on the findings of this and a previous study (Vingren et al., 2010) it seems clear that the use of a counter-balance system should not be used during maximal power assessments since such as system affects the performance measures obtained. Furthermore, when possible, use of a counter-balance system should be avoided during training since it alters the dynamics of the movement and thus possibly could affect training outcomes.
APPENDIX A

INFORMED CONSENT FORM
Before agreeing to participate in this research study, it is important that you read and understand the following explanation of the purpose, benefits and risks of the study and how it will be conducted.

**Title of Study:** Effects of using a counter-balance weight device during full movement bench throw performance testing

**Principal Investigator:** Jakob Vingren, Ph.D., University of North Texas (UNT) Department of Kinesiology, Health Promotion and Recreation.

**Purpose of the Study:** You are being asked to participate in a research study which will examine if the use of counter-balance weights affects the results of bench press throw measures.

**Study Procedures:**

**Overview:** You will be asked to complete 2 sessions separated by 7 days. In session 1 you will be familiarized with the study procedures and your maximal strength in the bench press exercise will be measured. In session 2 you will complete 8 separate maximal bench throw tests.

**Inclusion/exclusion criteria:** To be included in this study you must fill out a medical health questionnaire so we can minimize the risk of possible pre-existing medical conditions that may put you at risk during strength testing exercises or that might influence the outcomes of this study. Such criteria will include, but may not be limited to, heart conditions, blood pressure problems, muscle or skeletal problems, or conditions that would limit the range of motion about the shoulder or elbow joint. In addition you must be able to bench press 180 pounds.
**Session 1:** Upon arrival to the lab your height and weight will be measured. Then you will warm up using a standardized protocol of dynamic upper body stretches. You will be taught the correct technique for performing the bench press exercise using a Smith Machine. Once you can perform the bench press exercise with correct technique, we will measure your one-repetition maximum (1-RM) strength in the bench press exercise. After a rest period of 10 minutes you will be familiarized with full movement and push only bench press throw exercises and will practice them with 30% of your bench press 1-RM. You will perform 1 set of 2 repetitions of full movement and push only bench press throws with 5 minutes of rest between each exercise. During bench press throws, you will lie down on the bench of the Smith machine. For the full movement bench press throw you will hold the barbell with the elbows extended and then rapidly lower the barbell and immediately throw it upward as fast as you can. For the push only bench press throw the barbell will be placed on the safety stops at the level of your chest, and then you will throw it upwards as fast as you can. During both full movement and push only bench press throws the bar will be caught by research personnel after each attempt and slowly lowered until you are ready to complete the next attempt. You will be instructed not perform any upper body exercise for 48 hours prior to the next testing session.

**Session 2:** This session will begin with the same warm up as the first session followed by 2 repetitions of full movement and push only bench press throws at 30% bench press 1-RM. After a rest period of 5 minutes the testing will begin. You will complete eight bench throw tests of 2 repetitions each separated by 5 minutes. Two tests will used for
each of four different conditions 1) counter-balance weight-full movement bench throw, 2) counter-balance weight-push only bench throw, 3) no counter-balance weight-full movement bench throw, and 4) no counter-balance weight-push only bench throw. Velocity, force, power will be measured during the throws. Muscle activation will be measured using electromyography (EMG). This will consist of small electrodes placed on your chest and arm muscles of the right of your body.

Your participation in this study will take about 1 hour of your time for each visit.

Foreseeable Risks: The potential risk for an injury during this study is very small; however, performance of muscular exercise and physical effort can entail potential hazards of injury from over-exertion and/or accident. This study will be planned to avoid such injury. As with all exercise there is a slight risk for overexertion of the heart; this risk will be minimized by the medical screening that is designed exclude the rare individual for whom exercise might be harmful. Every effort will be made to make this investigation safe for participation through subject familiarization, experienced personnel, warm-up and cool-down (i.e., stretching and low intensity activity-specific exercise), technique instruction and practice, supervision, screening, monitoring and individualized exercise testing. All of these factors, including those previously outlined, should dramatically contribute to a reduction, if not an elimination, of any potential risks associated with this study.
Benefits to you or Others: We expect that the direct benefit to you from participating in this study will be limited; but we will explain your results to you so you can gain maximal education benefit from your participation.

Compensation for Participants: No compensation is offered for participation in this study.

Procedures for Maintaining Confidentiality of Research Records: All data will be kept in coded participant files in the primary investigator's locked files. Participant codes will be used when statistical analyses are performed or when experimental feedback sheets are provided to you. All investigators, professional staff, and technicians are aware of the confidentiality involved with this study and have completed the confidentiality training required by the University. Your data will not be available or divulged to anyone outside of the experimental research team. The data files will be kept for 3 years after the study is terminated. The confidentiality of your individual information will be maintained in any publications or presentations regarding this study.

Questions about the Study: If you have any questions about the study, you may contact Dr. Jakob Vingren or Harsh Buddhadev.

Review for the Protection of Participants: This research study has been reviewed and approved by the UNT Institutional Review Board (IRB). The UNT IRB can be contacted at (940) 565-3940 with any questions regarding the rights of research subjects.

Research Participants’ Rights:
Your signature below indicates that you have read or have had read to you all of the above and that you confirm all of the following:

• Dr. Jakob Vingren or Harsh Buddhadev has explained the study to you and answered all of your questions. You have been told the possible benefits and the potential risks and/or discomforts of the study.
• You understand that you do not have to take part in this study, and your refusal to participate or your decision to withdraw will involve no penalty or loss of rights or benefits. The study personnel may choose to stop your participation at any time.
• You understand why the study is being conducted and how it will be performed.
• You understand your rights as a research participant and you voluntarily consent to participate in this study.
• You have been told you will receive a copy of this form.

________________________________                                                             Printed
________________________________                                ____________
Name of Participant                                      Signature of Participant                                      Date

For the Principal Investigator or Desigee:

I certify that I have reviewed the contents of this form with the subject signing above. I have explained the possible benefits and the potential risks and/or discomforts of the study. It is my opinion that the participant understood the explanation.

____________________________________________________                                    ____________
Signature of Principal Investigator or Desigee                 Date
APPENDIX B

UNT EXERCISE PHYSIOLOGY LABORATORY MEDICAL HISTORY QUESTIONNAIRE
# UNT Exercise Physiology Laboratory Medical History Questionnaire

## Study Information

- **Subject #**

## Personal Information

- **Name**
- **Sex**
- **Age**
- **DOB**
- **Street**
- **City**
- **State**
- **Zip**
- **Phone**
- **Email**

## Medical History

**PLEASE ANSWER ALL OF THE FOLLOWING QUESTIONS AND PROVIDE DETAILS FOR ALL "YES" ANSWERS IN THE SPACES AT THE BOTTOM OF THE FORM.**

<table>
<thead>
<tr>
<th></th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Has your doctor ever said that you have a heart condition <strong>and</strong> that you should only do physical activity recommended by a doctor?</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Has your doctor ever denied or restricted your participation in sports or exercise for any reason?</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Do you ever feel discomfort, pressure, or pain in your chest when you do physical activity?</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>In the past month, have you had chest pain when you were not doing physical activity?</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Do you lose your balance because of dizziness or do you ever lose consciousness?</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Does your heart race or skip beats during exercise?</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Has a doctor ever ordered a test for your heart? (i.e. EKG, echocardiogram)</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Has anyone in your family died for no apparent reason or died from heart problems or sudden death before the age of 50?</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Have you ever had to spend the night in a hospital?</td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Have you ever had surgery?</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Please check the box next to any of the following illnesses with which you have ever been diagnosed or for which you have been treated.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High blood pressure</td>
<td>Elevated cholesterol</td>
</tr>
<tr>
<td></td>
<td>Asthma</td>
<td>Epilepsy (seizures)</td>
</tr>
<tr>
<td></td>
<td>Bladder Problems</td>
<td>Anemia</td>
</tr>
<tr>
<td></td>
<td>Coronary artery disease</td>
<td>Lung problems</td>
</tr>
<tr>
<td>12.</td>
<td>Have you ever gotten sick because of exercising in the heat? (i.e. cramps, heat exhaustion, heat stroke)</td>
<td></td>
</tr>
<tr>
<td>13.</td>
<td>Have you had any other significant illnesses not listed above?</td>
<td></td>
</tr>
<tr>
<td>14.</td>
<td>Do you currently have any illness?</td>
<td></td>
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<tr>
<td>15.</td>
<td>Do you know of any other reason why you should not do physical activity?</td>
<td></td>
</tr>
<tr>
<td>16.</td>
<td>Please list all medications you are currently taking. Make sure to include over-the-counter medications and birth control pills.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Drugs/Supplements/Vitamins</th>
<th>Dose</th>
<th>Frequency (i.e. daily, 2x/day, etc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

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42
17. Please list all allergies you have.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

18. Have you smoked? If yes, #/day

Cigarettes

Cigars

Pipes

Age Started

If you've quit, what age?

19. Do you drink alcoholic beverages? If yes, how much? How often?

20. Do you have a family history of any of the following problems? If yes, note who in the space provided.

- High blood pressure
- High cholesterol
- Diabetes
- Heart disease
- Kidney disease
- Thyroid disease

21. Please check the box next to any of the following body parts you have injured in the past and provide details.

- Head
- Neck
- Upper back
- Lower back
- Chest
- Hip
- Thigh
- Knee
- Ankle
- Foot
- Calf/shin
- Shoulder
- Upper arm
- Elbow
- Hand/fingers

22. Have you ever had a stress fracture?

23. Have you ever had a disc injury in your back?
24. Has a doctor ever restricted your exercise because of an injury?

25. Do you currently have any injuries that are bothering you?

26. Do you consider your occupation as?  
   - Sedentary (no exercise)
   - Inactive-occasional light activity (walking)
   - Active-regular light activity and/or occasional vigorous activity (heavy lifting, running, etc.)
   - Heavy Work-regular vigorous activity

27. List your regular physical activities

<table>
<thead>
<tr>
<th>Activity</th>
<th>How often do you do it?</th>
<th>How long do you do it?</th>
<th>How long ago did you start?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

ADDITIONAL DETAILS:

Atwood, G. (1784). A treatise on the rectilinear motion and rotation of bodies; with a description of original experiments relative to the subject. Cambridge, UK: Archdeacon.


