THE EFFECT OF HAND-HELD WEIGHTS ON VERTICAL TAKE-OFF VELOCITY DURING A COUNTERMOVEMENT JUMP

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University of Saskatchewan
Saskatoon

By
Ryan George Dueck
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ABSTRACT

THE EFFECT OF HAND-HELD WEIGHTS ON VERTICAL TAKE-OFF VELOCITY DURING A COUNTERMOVEMENT JUMP

The primary purpose of this study was to determine the effect that 2 lb and 5 lb hand-held weights had on vertical jump performance as assessed by vertical take-off velocity. Secondary analyses were conducted to provide additional insight into the observed results. Thirty-one male athletes performed three countermovement jumps (CMJ) with an arm-swing under three different treatment conditions: holding a 2 lb hand weight in each hand (CMJ2), holding a 5 lb weight in each hand (CMJ5), and without holding onto any weight (CMJ0). All jumps were performed on a forceplate, which permitted the calculation of vertical take-off velocity ($v_{to}$), average force during the upward jump phase ($avgforce_{up}$) and the duration of the upward jump phase ($time_{up}$). A repeated measures ANOVA was used to test for significant differences between the three treatment conditions for both the primary and secondary analyses. The primary analysis indicated that CMJ2 and CMJ5 exhibited significantly greater take-off velocities and thus, jump heights, than CMJ0. However, CMJ2 and CMJ5 were not significantly different from each other ($p<0.05$). The secondary analyses revealed that $time_{up}$ was significantly greater between the three treatment conditions and that $avgforce_{up}$ decreased from CMJ0 to CMJ5. An increase in the duration of the upward jump phase appears to be the primary contributor in enhancing vertical jump height with hand weights. These results indicate that increases in vertical jump height can be facilitated by the use of optimized magnitudes of hand weights.
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This thesis is dedicated to my wife, Shauna, for her never-ending motivation, love and understanding throughout my life, and to Sydney and Megan for their quiet inspiration. I would also like to express a heartfelt ‘thank you’ to my parents for their constant love, support and encouragement.
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Chapter One

SCIENTIFIC FRAMEWORK

1.1 INTRODUCTION

For the past 50 years, a variety of techniques and training strategies have been researched and implemented with the goal of improving vertical jump height. A common method that athletes use to enhance jump height during a countermovement jump (CMJ) is to perform an arm-swing because it allows for greater ground reaction forces to be produced, which results in an increase in the net impulse of the jumper. (Shetty and Etnyre, 1989; Harman, Rosenstein, Frykman and Rosenstein, 1990). By using the impulse-momentum relationship it can be shown that generating a greater net impulse (force x time) results in an increased take-off velocity of the centre of mass (CM) of the jumper. In turn, a higher take-off velocity enhances the height that the CM will travel after take-off. Because impulse is the product of force and time, changing either of these variables throughout the course of the upward movement of a CMJ will alter one’s jump height. Research has shown that using an arm-swing will allow jumpers to exhibit greater ground reaction forces in the same amount of time that it takes to perform a CMJ without an arm-swing (Harman et al., 1990; Feltner, Fraschetti and Crisp, 1999). Feltner et al. (1999) examined jumps with and without arm-swings using force-plate data and video-based coordinate data and
concluded that the arms slowed the counterclockwise rotation of the trunk and placed the extensor muscles of the hip in an advantageous position to generate larger torques. This resulted in a greater net impulse and, thus, greater jump heights.

At first glance, it would appear that adding weight to a jumper would be counterproductive. Indeed, research has shown that weighted vests around the trunk or weights placed on the ankles of various magnitudes will decrease the peak vertical jump height attained (Corwin, Zatiorisky and Fortney, 1998; Driss, Vandewalle, Quievre, Miller and Monod, 2001). However, using hand weights during the arm-swing of a CMJ has yet to be examined. The expectation is that adding a hand weight during a CMJ will increase the net impulse and, thus, the height jumped. Because the arm-swing has been shown to take advantage of the force-velocity properties of the muscle, it can be theorized that adding hand weight would decrease the velocity of the arm-swing and result in greater reactive forces produced over time at the shoulder. In turn, these increased reactive forces at the shoulder may slow the velocity of the hip extensors further and allow them to generate higher forces over time throughout the jump than if no hand weight was used. Thus, a jumper using hand weights would be expected to exhibit a greater force and increase the total duration of the jump due to the slowed contraction velocity of the arms. This would result in a greater net impulse and allow for a greater peak jump height. This paper will examine whether the addition of hand weights during the arm-swing of a CMJ will have an effect on take-off velocity.
1.2 REVIEW OF LITERATURE

The purpose of this literature review is to examine the effect of hand weights on the take-off velocity attained by the CM during a CMJ. The review will begin with an examination on the mechanics of a CMJ followed by a review of the contribution that an arm-swing makes to the peak vertical height of a CMJ. Finally, theories will be presented to establish a relationship between hand weights and peak vertical height in a CMJ.

1.2.1 Impulse-Momentum Relationship in Vertical Jumping

The CMJ is defined as starting in an initial standing position and performing a downward movement by bending the knees prior to commencing the upward jump phase (Harman et al., 1990). The upward movement is achieved by generating a reactive impulse against the ground so as to drive the body’s centre of mass (CM) in the upward direction. This is produced by the summation of muscular torques generated about the joints (Lees & Barton, 1996). Newton’s second law states that the rate of change of momentum of a body is proportional to the force causing it and the change takes place in the direction in which the force acts (Hay, 1993). In vertical jumping, there are two external forces acting in the vertical or \( y \) direction: the ground reaction force (GRF) applied by the subject’s feet and the weight (W) of the jumper (Figure 1.1). The GRF reflects the force that acts on the CM in an upward or positive direction and the weight acts in a downward or negative direction. The sum of these two forces, known as the resultant force (\( F_R \)), is equal to the product of the mass (m) and the acceleration (a) of the jumper’s CM.
Figure 1.1 Free body diagram of the two vertical external forces, weight (W) and ground reaction force (GRF), that act on the jumper during a CMJ
(GRF - W) = F_\text{R} = ma_y \quad (1.1)

Throughout the duration of a CMJ, weight remains constant but the GRF changes due to the varying amounts of force produced by the muscles (Figure 1.2). Adding these forces together for every moment in time yields a resultant force (F_R) that changes continually throughout the course of a CMJ (Figure 1.3). Because the resultant force (F_R) changes continually over time (t), researchers often use the impulse-momentum relationship to evaluate the jump height.

\[ \int F_\text{R} \, dt = m(v_{\text{to}} - v_i) \quad (1.2) \]

The left hand side of this equation is known as the impulse and can be thought as the area under the force-time curve. The product of mass and change in velocity on the right hand side of the equation is the momentum of the object. The final velocity, or take-off velocity (v_{\text{to}}) is measured just as the feet leave the ground, and the initial velocity is the velocity while the jumper is in an initial static position and, therefore equals zero. This relationship is important in vertical jumping because a change in impulse means a change in the jumper’s take-off velocity (mass is constant), and a greater take-off velocity results in a greater height reached by the CM after take-off. This can be illustrated by using projectile motion equations. Once the jumper’s feet leave the ground only gravity and air resistance (negligible) act on the jumper. By considering the jumper to be a projectile, the jump height of the CM can be calculated if the take-off velocity is known.
**Figure 1.2** Force-time profile of the two external vertical forces, weight ($W$) and ground reaction force (GRF), that act on a jumper during a CMJ.

**Figure 1.3.** Force-time profile of the resultant force ($F_R$) acting on a jumper during a CMJ.
\[ v_f^2 = v_{to}^2 + 2g\Delta s \]  \hspace{1cm} (1.3)

where \( v_f \) = the final vertical velocity at the apex of the jump, \( v_{to} \) = take-off velocity, \( g \) = acceleration due to gravity, \( \Delta s = \) CM change in displacement (maximum height reached by the CM minus CM height at take-off). Because the final velocity is zero (CM is at peak height), the equation can be rearranged to be:

\[ \Delta s = \frac{v_{to}^2}{2g} \]  \hspace{1cm} (1.4)

or:

\[ s_f = s_i + \frac{v_{to}^2}{2g} \]  \hspace{1cm} (1.5)

Although it is evident that the peak height (\( s_f \)) reached by the jumper’s CM is primarily dependent on the take-off velocity of the jumper, it should be noted that this calculation is also dependent on the height of the CM at take-off (\( s_i \)). Thus, if two jumpers exhibited similar take-off velocities and CM take-off positions, the maximum height that each jumper’s CM attained would be the same. However, if the CM position at take-off differed while the take-off velocities remained the same, the jumper whose CM was higher at take-off would exhibit a greater absolute peak jump height. Aragon-Vargas and Gross (1997) used video records and markers to measure the CM at standing and at the peak height after take-off during a CMJ without an arm-swing. They defined vertical jump performance as peak vertical position of the CM during flight, minus the CM height while standing as it was assumed that the height of the CM
at take-off was similar to the height when standing. They found that take-off velocity was highly correlated with vertical jump performance ($r = .96$). This illustrates that take-off velocity is not 100% correlated with the absolute peak height of the CM because the height at take-off may differ from one jump to another. However, it is very difficult to note the exact position of the CM at take-off without video data so researchers often assume that it is negligible and equate a greater take-off velocity to greater jump heights.

Impulse is expressed graphically as the area under the force-time curve and, in order to achieve a greater take-off velocity, a greater net impulse is required by the jumper. Figure 1.4 illustrates three areas of a typical force-time curve of a CMJ. During the unweighting phase of a CMJ, the force falls below the body weight for a short period of time (Area A). Dowling and Vamos (1993) refer to this area as the negative impulse. Area B is part of the positive impulse that occurs from the time after Area A until the jumper is at the low point, which is also the point in which Areas A and B are equal. Areas A and B cancel one another and the remaining impulse (Area C), known as the net impulse, is what determines the jumper’s take-off velocity. This means that greater forces can be applied over a short period of time or smaller forces can be applied over a long period of time to produce similar take-off velocity values (Voigt, Simonsen, Dyhre-Poulsen and Klausen, 1994). In summary, when the forces involved in the jump are increased or decreased over time, a proportional increase or decrease in take-off momentum occurs and this alters the peak height reached by the CM. Therefore, when examining a technique or strategy used to increase jump height, such as an arm-swing, it is important to determine the effect that it
Figure 1.4 Typical resultant force-time curve and areas under the curve for the CMJ during the ground contact phase.
has on impulse or momentum because it may help researchers understand why arm-swing contributes to peak jump height. If the mechanisms responsible for increased height with an arm-swing are identified, theories can be developed to determine the effect of hand weights on a CMJ.

1.2.2 Work-Energy Theory

An alternate equivalent mathematical model that can be used to analyze jumping is the work-energy approach. Rather than examine the resultant force applied over time, some authors examine the resultant force applied over a displacement ($s$) of the body's CM. This is a measure of the external work done (Hamill and Knutzen, 1995).

$$\text{Work} = \int F_x ds \quad (1.6)$$

The external work can only be done if there is displacement of the CM as a result of the net external forces. In the vertical jump, the muscles of the lower extremities produce a force (GRF) that displaces the CM, thereby performing work upon the jumper (Barham and Shetty, 1987). Positive work occurs when the displacement of the CM and the resultant force act in the same direction and negative work occurs when they are in opposite directions. In a CMJ, the jumper does positive work during the unweighting phase and during the upward phase of the jump (Areas A and C, respectively in Figure 1.4). Negative work occurs when the jumper exhibits positive forces while moving downward (Area B in Figure 1.4).
1.2.3 Average and Instantaneous Power

Average power refers to the rate of doing work or the amount of time it takes to perform a certain amount of work (Winter, 1990).

\[
\text{Power} = \frac{\Delta \text{work}}{\Delta \text{time}} \tag{1.7}
\]

An individual who completes a given quantity of work in a shorter period of time is said to have a greater average power output. By rearranging equation 7, one can derive an expression of instantaneous power. Because the displacement is the area under the velocity-time curve the definition of work becomes:

\[
W = \int Fds = \int Fvdt = \int (Fv)dt \tag{1.8}
\]

Substituting this into equation 7:

\[
P = \frac{d(\int Fvdt)}{dt} \tag{1.9}
\]

Therefore, instantaneous power can be written as:

\[
\text{Power} = \text{Force} \cdot \text{velocity} = F \cdot v \tag{1.10}
\]

In vertical jumping an instantaneous net force at each time interval is applied by both gravity and the lower extremities (GRF), which in turn imparts a velocity (v) on the CM. The product of these two variables is the instantaneous power output (P) of the athlete. Anything affecting the force output or the vertical velocity of an individual will alter the instantaneous power. During the CMJ, peak instantaneous power is generated through the optimal combination of GRF and velocity. This is important because researchers have found very high correlations between peak power and peak jump height. Dowling and Vamos
(1993) examined university students and found correlations of .92 while Harman et al. (1990) discovered similar correlation \((r = .91)\) with physically active males who performed CMJ with an arm-swing. These findings are useful as they illustrate the importance of implementing training programs to increase not only muscle strength but also increase strength specifically at high velocities. However, the results give very little insight into the specific aspects of performance that distinguish one jumper from another. Aragon-Vargas and Moss (1997) found that peak joint powers and hip torques were the main factors that distinguished skilled jumpers from unskilled jumpers. They explained that this might have been due to differences in muscle fiber type composition (Bosco and Komi, 1979) or coordination strategies that allow the muscle to act at a more advantageous range of the force-velocity curve.

Although peak power is so closely associated with jump height, using it as a measure of one’s jumping ability should be cautioned because it may be possible to increase the vertical impulse without changing the peak power. Driss, Vandewalle, Quievre, Miller and Monod (2001) examined the effects of weighted vests (0, 5 and 10 kg) on peak jump height and peak power in sedentary individuals and power and strength trained athletes. In all of the groups, the force corresponding to the peak instantaneous power increased and the velocity corresponding to the peak instantaneous power decreased with the increased load. Their results also indicated that an increase in vest load of 5 kg decreased the take-off velocity in all subjects but peak power did not change significantly in the athletic groups. This means that different strategies of
individuals could alter the peak jump height through changes in vertical impulse patterns but that the peak power may not change.

1.2.4 Arm-swing Effects on Jumping Mechanics

The arm-swing is used in a variety of sports and the amount of movement performed by the arms is very much dependent on the skill being performed. For example, a volleyball block requires that the arms be held in a 'ready' position, where the hands are at or above the level of the head. This is done to allow the athlete to perform a quicker movement since keeping the arms at the side or performing a back swing may not allow enough time for the blocker's hands to be ready to block an attack. In other sports such as high jump or diving, the arms are swung backward and then forward during the upward phase to elicit high ground reaction forces. Harman et al. (1991) describe the arm-swing in a CMJ as swinging the arms back while letting the body drop and the knees bend until the CM of the jumper is at it's lowest point. The arms are then accelerated in a forward, upward arc while the jumper performs the upward movement. Although there is no specific research protocol for performing an arm-swing, the majority of studies that examine CMJ's with an arm-swing use the one described above (Komi and Bosco, 1978; Feltner et al., 1999).

When examining the contribution that the arms make to take-off velocity, researchers use the impulse-momentum relationship to determine the effects that arm-swing has on the duration of the jump and the ground reaction forces that are generated. Harman et al. (1991) compared the effects of an arm-swing in a CMJ and found that the duration of the jump did not change significantly but the peak vertical ground reaction forces and the net vertical impulses were increased.
by about 10%. Shetty and Etnyre (1989) found similar results in that peak force, work and peak power were significantly greater in jumps performed with an arm-swing. Research by Feltner et al. (1999) revealed that the arm-swing raised the body's CM by 3% of standing height at take-off (an average increase of 6 cm) and the vertical velocity at take-off was 12.7% greater (an average increase of 8.2 cm) than the CMJ's performed without an arm-swing. They calculated the peak heights attained and found that the arm-swing added approximately 14.3 cm to the peak height of the body's CM during a CMJ. Lees and Barton (1996) assessed the contribution of the limb's relative momentum to the peak total body momentum and concluded that the arms contributed to 12.7% of the peak total body momentum. The authors argued that segment momentum could be considered to have two parts. The first part, termed transfer momentum, is due to the motion of the body to which that segment is attached. For example, the arms are attached to the trunk and as the trunk is raised the arms are raised with it, giving the arms momentum. The second part is the relative momentum, which is due to the motion of the arms relative to the shoulder joint. It is this momentum that identifies the specific contribution that arm movement makes to the total vertical body momentum. In a CMJ, the arms acquire momentum as they accelerate upward and when this movement decelerates or stops near take-off, the momentum is shared with the total body, and the total body will take on the momentum of the arms. Since the body has a much greater mass than the arms, it will not assume as great a velocity as the arms had but the contribution of the arms is still evident.
As momentum is proportional to the impulse generated, an increased momentum of the body means that the arms allowed for greater forces to be produced over a period of time. According to Newton’s third law, every action has an equal and opposite reaction. Therefore, it can be assumed that the upward acceleration of the arms must be accompanied by a force of equal magnitude at the feet, resulting in an increased ground reaction force. However, Harman et al. (1990) have suggested that this is not the case because they observed that the arms decelerate relative to the rest of the body as they approach the raised position before take-off. According to the authors, this means that the arms return to zero velocity relative to the rest of the body before take-off and the net effect on the net impulse should be zero. Although this theory is accurate when an individual is in the air, it is not a valid statement when an individual swings the arms upward while standing on the ground. When an individual stands on the ground and accelerates the arms in the upward direction, the concomitant downward movement is met with resistance at the ground. This results in an increased reactive force at the feet. While in the air, the concomitant downward movement is not met with any resistance and, therefore, the net force is zero. Although it is evident that the arms impose a reactive force at the ground, they also exert forces on other joints more directly involved in propelling the body upward during a CMJ. These reactive forces change the contraction velocity of the muscles involved with extending the body upward, which results in an increased force (Feltner et al., 1999). It is therefore necessary to examine the physiological properties of the muscle in order to determine how swinging the arms can influence their force-generating capacities.
1.2.5 Arm-swing Effects on the Force-Velocity Properties of Leg Muscle

A CMJ involves three types of muscle contraction of the lower body: the eccentric contraction, the isometric phase and the concentric contraction. The eccentric and concentric contractions produce different force outputs at different contraction velocities. The isometric contraction is assumed to occur when the muscle is active and develops tension but with no external change in joint position. Thus, velocity of muscle sarcomeres is assumed to be zero.

A concentric contraction occurs when a muscle generates tension actively with shortening the length of the muscle (Komi, 1984). During a CMJ, the concentric phase occurs during the CM rise in the upward direction. In a concentric movement muscle fibers shorten at a specific velocity while producing a force used to move a segment or external load. At slower velocities the force output from a maximal contraction effort is greater than at higher velocities. This can be explained using the sliding filament theory (Hill, 1953).

At the microscopic level, the myofibrils of the muscle containing thick myosin and thin actin filaments constitute the contractile unit of the muscle known as the sarcomere (Figure 1.5). During the shortening of a sarcomere, the myosin binds to sites on the actin filament to form a cross-bridge. When a myosin molecule binds to an active site, this triggers a change in the tilt angle between the arm and head of the myosin molecule. The rotation of the cross-bridge provides the power stroke, which drags the thin filament towards the center of the thick filament (Figures 1.5 and 1.6). After the rotation of the cross-bridge is complete, the head dissociates from the active site and returns to its original tilt angle and attaches to another active site. The simultaneous sliding of a number of
Figure 1.5 Longitudinal diagram of a contracting sarcomere showing the relationships between thick (myosin) and thin (actin) myofilaments.

Figure 1.6 Diagram illustrating the power stroke of the myosin pulling the actin filament towards the centre during the shortening of a sarcomere.
sarcomeres creates a change in length and force in the muscle and the amount of force that can be developed is proportional to the number of cross-bridges formed.

The hyperbolic shape of the whole muscle force-velocity relationship for concentric contractions results from the combined contributions of all of the active crossbridges (Figure 1.7). If the sarcomere shortens at a fast velocity, the cycling rate of the cross-bridges will have to be increased. The myosin heads sliding by the actin site remain for increasingly shorter periods of time and may not bind to the actin. Therefore, the sarcomere can exert less force with increasing velocities of shortening because fewer cross-bridges attach and contribute to force output at any moment in time. Figure 1.7 illustrates that peak force is produced when velocity is zero because there are a maximum number of cross-bridges that contribute to the force output at one time. As the velocity increases, the cycling rate of cross-bridges is greater, which decreases the force because fewer cross-bridges are attached at one time. Thus, in a concentric contraction, velocity is increased at the expense of a reduction in force, and vice versa. This concept is important to the vertical jump because swinging the arms takes advantage of these properties during the course of a CMJ. Feltner et al. (1999) collected video-based coordinate data and ground reaction forces of 25 volleyball players performing CMJ's with and without an arm-swing. In their analysis the authors divided the upward or propulsive phase into three equal time periods. During the first two time periods of the propulsive phase, they found that the jumpers began the upward movement by rotating the trunk in a
Figure 1.7 The force-velocity relationship of the muscle.
counterclockwise direction and accelerating the arms forward and upward relative to the trunk. It was theorized that the shoulder muscles created large counterclockwise torques on the arms relative to the trunk during the upward arm-swing (Figure 1.8 A). In turn, a reactive clockwise torque of equal magnitude was produced at the shoulder, which opposed the counterclockwise rotation of the trunk. As a result, the hip extensors producing the rotation of the trunk experienced slower contraction velocities than if no arm-swing was performed (Figure 1.8 B). The slower contractions resulted in a greater hip extensor torque and, thus, greater forces during the upward phase of the CMJ with an arm-swing. Because the temporal data indicated that the time from the CM at the low point to the CM at take-off were identical, it was concluded that the increase in net impulse was due to the greater forces produced during the arm-swing, and that the enhanced forces resulted from the change in the force-velocity properties created by the arm-swing. During the last third of the propulsive phase, it was found that the arms decelerated near the end of the swing and pulled up on the rest of the body, which caused the quadriceps and hip extensors to contract more rapidly. The authors indicated that although this would diminish their force-generation capacities, the knees and hips were almost fully extended and the muscles are not in a position to generate much positive vertical ground reaction forces.

An eccentric muscle action is a lengthening in the muscle when it is subjected to an external force greater than the internal force within the muscle. The eccentric muscle action is the downward movement or pre-stretch during the
Figure 1.8 Free body diagram illustrating the effects of an arm-swing on hip extensor force during the upward movement of the CM. In figure A, the trunk rotates counterclockwise at an angular velocity ($\omega_{tr}$), while simultaneously the shoulder muscles generate a counterclockwise torque on the arms ($\tau_{shldr}$). As a result of this arm-swing, an equal and opposite clockwise torque ($\tau_{tr(shldr)}$) is produced on the upper portion of the trunk, which slows the rate of hip extension (B).
execution of a CMJ and the force-velocity relationship during the eccentric phase is opposite to that seen when the muscles act concentrically. When the velocity of a muscle increases there is an increased force output. This arises from the time-dependent crossbridge cycling properties. Because detachment requires a finite interval of time, increasing stretch velocities over increasingly greater lengths before they can detach will extend the elasticity associated with an attached crossbridge. Because of the elastic nature of the crossbridges, a greater extension leads to a larger force being generated by each attached crossbridge. This effect is ultimately limited by factors similar to that for shortening muscle. For example, the time during which the crossbridge is within binding proximity to the actin sites decreases with stretch velocity, so the average number of bound crossbridges decreases. The eccentric movement is important when evaluating a CMJ because it is performed prior to the concentric phase of the jump, which means that the extensor muscles are activated before upward movement occurs.

1.2.6 Arm-swing Effects on the Stretch Shorten Cycle

During the downward movement of a CMJ, leg muscles contract eccentrically and are simultaneously stretched prior to contracting concentrically during the upward phase. This combination of eccentric and concentric contractions is known as the stretch-shorten cycle (SSC) and research has shown that positive work output is enhanced when a prestretch is performed (Cavagna, 1977). For example, performing a CMJ results in greater peak forces and increased jump heights than when performing a squat jump (SJ), where the jumper begins in a stationary semi-squatted position prior to commencing the upward jump phase (Asmussen and Bonde-Peterson, 1974; Komi and Bosco,
The SSC can be described using simple muscle modeling that incorporates a contractile component (CC) and a series elastic component (SEC). The contractile component is the basis of all active behavior of muscle (Komi, 1991) and the SEC is in series with the contractile components of the muscle (Figure 1.9). The SEC is quasi-conservative, which means that mechanical energy delivered by the CC will be taken up by the SEC and returned to the surroundings as the SEC returns to its original condition. A portion of series elasticity resides in the tendon while the remainder is believed to be in the cross-bridges between actin and myosin filaments. There are two important aspects that should be considered when examining the model: 1) The CC and the SEC must be added together to obtain the total length of the entire muscle-tendon complex and 2) Force exerted by the CC is always equal to the force maintained in the SEC. A concentric contraction is assumed to be preceded by an isometric type of contraction with rearrangements of lengths of contractile and series elastic elements. In an isometric contraction measured externally, the total muscle-tendon length remains at a constant length while the SEC and CC change during force fluctuations. As the CC produces more force, the SEC stretches which leads to a shortening of the CC. When the pulling force of the CC on the SEC equals, or slightly exceeds, that of the load, the movement of the joint occurs. Figure 1.10 illustrates the difference in the contraction dynamics between the starting position of a squat jump and a position of similar joint angles of a CMJ where the jumper is at the low point (zero velocity). The entire muscle-tendon complexes are the same length but the SEC is longer and the CC
Figure 1.9. Mechanical model illustrating the series elastic components (SEC) and the contractile component (CC) of the active plantar flexors.

Figure 1.10 At the same total muscle length ($S_0$) at the onset of a concentric contraction the length of the contractile component (CC) will be shorter in the CMJ than the SJ due to larger stretch of the series elastic components (SEC).
is shorter in the CMJ, which indicates that more force is being delivered during the CMJ.

Physiologists have not been able to determine the exact cause of increased work in the shortening phase of a SSC movement but a number of mechanisms have been identified. Under *in situ* conditions it is difficult to positively identify mechanisms and even more difficult to determine the contribution that each one makes due to difficulties in measuring. In a target article by Van Ingen Schenau, Bobbert and de Haan (1997) four possible factors were identified to account for increased work output of the shortening phase. These included time available for force development, storage and reutilization of elastic energy, contractile component potentiation and stretch-reflex contributions. Bobbert, Gerritsen, Litjens and van Soest (1996) used a dynamic simulation model and five experienced jumpers performing countermovement jumps to determine the effect of each mechanism. It was concluded that the crucial contribution of the countermovement was that it allowed time for the muscles to build up a high level of active state before the start of shortening so that they were able to produce more work over the first part of their shortening distance. Due to the interaction between the CC and SEC and limitations in the rate at which the central nervous system generates control signals, the maximum force of the muscle takes time to develop (Winter, 1990). Before the CC begins to develop force the SEC needs to be stretched, which takes time. In a squat jump, shortening starts as soon as the level of muscle stimulation is increased above that required for maintenance of the starting position and, consequently, less force and thus less work is produced over the first part of the shortening
distance. Allowing the muscle to build up an active state with an eccentric contraction can avoid this undesirable effect (van Ingen Schenau, 1984; Avis, Toussaint, Huijing and van Ingen Schenau, 1986; Chapman and Sanderson, 1990).

When comparing CMJ's with and without arm-swings, Feltner et al. (1999) concluded that the arm-swing allowed the athletes to produce greater knee extensor torques by 28% during the time between the low point and midway through the upward phase despite increasing velocity of knee extension. The reason for greater knee extensor torque was unclear but the authors speculated that it might be due to muscle tension benefits associated with the previous stretch of the quadriceps during the back-swing of the arms. To date, there is little research examining the effects of the back-swing during the downward movement of a CMJ. Lees and Barton (1996) theorized that the large negative relative momentum as a result of the back-swing is converted into a large positive relative momentum during the upward phase of a CMJ, which makes a greater contribution to performance than if they started from rest. Although it is unclear how the back-swing may benefit the jumper during the eccentric contraction, there is evidence suggesting that a different load is imposed on the legs as the back-swing tends to result in less hip, trunk and knee angular displacement and negative velocities as well as decreased ground reaction forces at the low point of the jump (Feltner et al., 1999). This may be due to the backward swing of the arms partially offsetting the downward acceleration of the rest of the body, thus requiring a smaller deceleration to change direction as seen in CMJ's without an arm-swing (Harman et al., 1990). It is possible that a back-
swing, which imposes a decreased eccentric velocity of the CM, may benefit concentric performance. Blanpied, Levins and Murphy (1995) used three different eccentric/concentric speed combinations to examine the effects of concentric force during plantar flexion on a Kin-Com dynamometer. They also used EMG data to ensure that the plantar flexion force followed the lengthening-shortening sequence expected to occur in SSC movements. They found that a lower stretch speed resulted in higher shortening force values, which was opposite to what one would predict using traditional force-velocity relationship, and theorized that perhaps the slow-twitch muscle fibers in the soleus muscle reacted more favourably to the slower stretch (Bosco, Tihanyi, Komi, Fekete and Apor, 1982). It is currently unknown whether a reduction in CM eccentric velocity and stretch length during the back-swing of a CMJ is of a greater benefit to the upward phase than if no back-swing is performed.

1.2.7 Contribution of Hand Weights to Jump Height in a CMJ

There are currently no studies that examine the effects of hand weights with an arm-swing as seen in a typical CMJ. However, research by Yamazaki, Suzuki, and Mano (1992) evaluated the effects of arm lifting movements (ALM) on the flight time of five different vertical jump conditions. For each jump the muscles at the ankle joints were the only ones used for propulsion, which is quite different from a traditional CMJ where hip, knee and ankle joints are involved. Two jumps were performed with an ALM, where the subjects stood with the arms at their side with the elbows extended and rapidly moved their hands vertically. Of those two jumps one was performed without weight and one performed while holding a 4kg hand weight in each hand. The other two jumps
were performed without ALM with one having no weight and the other holding
the hand weight. Subjects also performed a CMJ at the plantar flexors without
weight or ALM. They found that the ALM with a weight increased the amount
of flight time, which was due to the increased momentum (mass x velocity)
added to the system. Although the velocity of the arms was traded off by an
increased resistance weight, the arm movement produced a greater momentum,
and thus a greater net impulse, because loaded muscles could produce greater
force for a longer duration. This reasoning could be applied to the typical arm-
swing seen in a CMJ. Swinging the arms forward with weight would result in
decreased velocity of the arms at the expense of a greater load, which would
increase the amount of time it takes to perform the entire jump. In addition,
greater ground reaction forces would also be expected due to the force-velocity
characteristics of the muscle. As the weighted arms swing forward at a reduced
velocity, the force that is generated by the shoulder muscles would increase and a
greater downward reactive force at the shoulder would be produced. As a result,
the concentric hip extensor velocity that rotates the trunk upward would slow
even further due to the increased downward resistance at the shoulder. This
would allow greater torques at the trunk to be produced over a longer period of
time than if no weight was used. However, there is a limit to which a greater
mass at the arms would result in greater jump heights. As the arms move
forward and upward during a CMJ, the vertical velocity of the arms is greater
than that of the rest of the body. If the load on the arms is too great the vertical
velocity of the body would surpass that of the arms and the hand weight would
become an additional load that the hip and leg muscles would need to lift.
Therefore, an optimal load or load range would be required to add momentum in the system with minimal trade-off in velocity of the arms in order for greater jump heights to occur. Figure 1.11 shows the hyperbolic shape of the force-velocity curve of the hip extensors under three hypothetical jump conditions and suggests that swinging the arms with weight allows the muscles to act in a more advantageous range of the curve. Condition A indicates that jumping without the arms does not allow for the hip extensors to be in a position of greater force-generating capacities due to the rapid concentric contraction, which was also evident in the research of Feltner et al. (1999). By swinging the arms, there is a reduced contraction velocity of the hip extensors and the forces that are generated are increased (Condition B). Finally, adding a hand weight to the system would slow the arm muscles to increase the total time of the jump and add greater reactive forces at the shoulder, which, in theory, would cause a further reduction in hip extensor velocity and increased force (Condition C). The same benefits would not be achieved if the load was placed only on the trunk as opposed to the arms. Although mass would be added to the body, the total momentum would not increase because the trade-off in velocity would be too great. There would be no transfer of momentum of the arms and the hip, knee and ankle extensors would have to perform more work in order to move the CM in an upward direction. In addition, there would be no further decrease in hip extensor velocity because the reactive forces produced at the arms would not change if the weight was added only to the trunk.
Figure 1.11 Hypothetical concentric force-velocity relationships of the hip extensors based on three different CMJ conditions. A = CMJ without an arm-swing; B = CMJ with an arm-swing; C = CMJ with an arm-swing while holding a hand weight.
Another way that the hand weights could elicit higher forces is through eccentric loading during the downward phase of the jump. There are a number of studies that examine the effects of loading the muscles eccentrically in order to determine the changes that occurs concentrically. A common way researchers load the muscle eccentrically is to have subjects jump from various heights. These drop jumps impose various stretch-load conditions on the muscles and create changes in the net impulse produced. Some researchers have reported an increase in positive work, force production and enhanced velocity of concentric movement with an increased dropping height (Clutch, Wilton, McGown and Bryce, 1983; Bobbert, Huijing and Van Ingen Schenau, 1987). However, there appears to be a limit in the amount of descent height that one can jump from in order to achieve greater jump heights, as the Golgi tendon organs inhibit concentric muscular activity after a certain drop height (Komi, 1983). Bobbert et al. (1987) used video and forceplate data to examine differences in force, peak power, jump height and joint moments between drop jumps and CMJ’s. Although there were minor differences in joint angles and angular velocities throughout the majority of the upward phase between the two conditions, the authors stated that it should not be assumed that the length and shortening velocity of the contractile parts of the muscle (i.e. CC and SEC) were also the same. For example, when comparing the two conditions for one subject during the last 75ms of the upward phase the plantar-flexing moment declined more rapidly during the drop jumps. The authors speculated that the SEC may have lengthened faster, which means that the CC contracted more slowly and a larger force and greater power output was exhibited during drop jumps. It could be
theorized that a hand weight may alter the CC and SEC to favour greater
centric forces despite similar joint angular displacements and velocities.
Loading the muscles with a hand weight may also allow for greater forces to be
produced throughout the downward phase of the CMJ and improve the potential
for greater ground reaction forces over the upward phase. The study by Bobbert
et al. (1987) showed that greater forces were exhibited at the start of the upward
phase in the drop jumps. According to Bobbert et al. (1996) the eccentric
movement provides time for the muscle to develop force and allows greater
starting forces to be produced than if no countermovement was performed. If a
hand weight could increase the amount of ground reaction force throughout the
downward phase the jumper would begin the upward phase at a larger starting
force than if no hand weight was used. This would mean that the potential to
improve the net impulse would be enhanced. Although eccentric loading has
been shown to increase ground reaction forces, a lack of research pertaining to
the downward phase of a CMJ makes it difficult to identify which specific
mechanisms, if any, would be responsible for enhanced vertical jump height.
1.3 STATEMENT OF PROBLEMS AND HYPOTHESES

1.3.1 Problems

1.3.1.1 Does the addition of hand weights during the arm-swing of a CMJ increase the take-off velocity of the jumper and, if so, are there differences in take-off velocities between 2 lb hand weights and 5 lb hand weights?

1.3.1.1. Are the differences in take-off velocity among the various jump conditions due to changes in average force or jump duration or both?

1.3.2 Hypotheses

1.3.2.1 Vertical take-off velocity will be increased using hand weights.

1.3.2.2 Five lb hand weights will be more effective in increasing vertical take-off velocity than 2 lb hand weights.

1.3.2.3 The duration of the upward phase will increase with the addition of hand weights.

1.3.2.4 The average force during the upward phase will increase with the addition of hand weights.

1.3.3 Assumptions

It was assumed that the subjects performed each jump with a maximal effort. It was also assumed that the subjects jumped as vertically as possible with little horizontal movement. It was assumed that the measures used in the study are valid measures of the construct they are designed to evaluate.
1.3.4 Limitations

Lack of experience in jumping with hand weights may make the CMJ0 treatment condition easier to perform, which may affect the results.

1.3.5 Delimitations

The results of this study can only be generalized to recreational and competitive athletes between the ages of 18 and 30 without lower or upper extremity injury.
2.1 RESEARCH DESIGN

A balanced repeated measures experimental design was used for this study. Each subject was instructed to jump under three treatment conditions: a CMJ with an arm-swing without holding onto hand weights (CMJ0), a CMJ with an arm-swing while holding onto a 2 lb hand weight in each hand (CMJ2), and a CMJ with an arm-swing while holding onto a 5 lb hand weight in each hand (CMJ5). Subjects performed three trials in a row on a forceplate under each treatment condition during the testing session. The trial with the highest take-off velocity under each treatment condition was selected for statistical analyses. For each session, a maximum of six subjects were tested and each subject jumped using a different order of treatment conditions so as to balance out any order effect.

Immediately prior to each testing session, an educational session was held for all subjects to familiarize themselves with the forceplate and testing procedures. A minimum of two practice jumps were performed under each treatment condition to allow subjects to become familiar jumping with hand weights. The education session is described in section 2.3.1.
2.2 SUBJECTS

Thirty-one male volunteers were recruited from Winnipeg recreational and varsity sport teams, organizations and clubs. Subjects were recruited through direct contact via email or telephone with the athletes and teams. Subject descriptive data is presented in Table 2.1. All subjects completed three jumps using each treatment condition and none dropped out of the study.

This study was approved by the University of Saskatchewan Advisory Committee on Ethics in Human Experimentation (Appendix A). All subjects signed a consent form (Appendix B) and were advised that they could withdraw at any time during the study.

Table 2.1 Subject descriptive characteristics (mean ± standard deviation)

<table>
<thead>
<tr>
<th>Number</th>
<th>Age (years)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>23 ± 2</td>
<td>85.5 ± 10.7</td>
<td>185.9 ± 11.8</td>
</tr>
</tbody>
</table>

2.2.1 Inclusion Criteria

1. Participation in any recreational or competitive sport for at least one season.
2. Male between the ages of 18 and 30.

2.2.2. Exclusion Criteria

1. Present or recent lower extremity injury that might inhibit jumping ability or become exacerbated during testing.
2. Inability to perform a CMJ with an arm-swing as instructed or perform a CMJ while holding onto hand weights in each hand.

3. Inability to perform three CMJ’s for each jump condition during the testing session.

2.3 PROCEDURES

All subjects were provided with an education session and an opportunity to practice the different jumps. Testing consisted of performing three jumps under each treatment condition for a total of nine jumps. The following subsection describes the testing procedures.

2.3.1 Education Session

Prior to each testing session, subjects were randomly assigned the order to which they would jump as well as order of the treatment conditions. They were then given information regarding the purpose of the study. Subjects were informed that the study involved examining the effects that hand weights had on the force-time profile of a CMJ. In order to prevent changes in effort under the jump conditions, subjects were not informed of the specific variables that were being examined. An explanation of a CMJ was provided followed by a demonstration by the researcher to allow subjects to familiarize themselves with the movement.

To date, there are no specific guidelines for performing a CMJ with an arm-swing but the literature does provide descriptions of a CMJ which were similar to that used in this study (Komi and Bosco, 1978; Harman et al., 1990). Because the term ‘countermovement’ can mean any movement in a downward direction, there are no specifications as to the time of downward movement or
countermovement distance required in order to classify the jump as a CMJ. Therefore, subjects were instructed to perform a jump with a downward movement prior to extending upward.

The jumpers in this study were asked to stand with their arms at their side and perform a back swing with the arms during the countermovement and to swing the arms forward and upward while extending upward.

The subjects practiced the movement under each condition. Each subject jumped a minimum of two jumps under each treatment condition in the predetermined order. All subjects were asked if they felt comfortable in performing the jumps in each condition and were encouraged to practice until they felt comfortable.

2.3.2 Testing Procedures

After the education session, subjects were weighed and tested on a Kistler forceplate in an Engineering Lab at the University of Manitoba. Each subject completed three jumps under each jumping condition (CMJ0, CMJ2, CMJ5) for a total of nine jumps.

2.3.2.1 Countermovement Jump

Prior to the start of each jump, subjects were reminded that each jump should be performed at a maximal effort and they should attempt to jump as vertically as possible and land approximately at the same location on the forceplate from where they started. For every trial, each subject was instructed to stand stationary with the arms at their side in the middle of the forceplate and wait for the researcher to give a verbal command to jump. Shortly before the starting command, the computer-based data acquisition was initialized by a
keystroke. Following this, a CMJ was performed with an arm-swing either while holding onto hand weights of 2 lbs., holding onto hand weights of 5 lbs., or without holding any weight in the hands. After a jump was completed by a subject, he would wait until the remainder of the subjects in that testing session completed a jump before performing his next jump. All three trials for one treatment condition were completed before moving onto the next treatment condition. A minimum rest period of two minutes between trials was provided for recovery, which has been deemed sufficient for recovery between maximal CMJ’s (Read and Cisar, 2001).

The vertical ground reaction forces were collected at a sampling frequency of 200Hz from a Kistler forceplate (9286 A) using Bioware software (version 3.21). Forceplates are commonly used to record vertical jump performance and have been shown to be a valid tool for research (Schieb, 1987; Hatze, 1998). For each jump, vertical take-off velocity, average ground reaction force, and duration of the upward jump phase were calculated from the force-time profile using a customized software program (Appendix C). The calculations were based on the impulse-momentum relationship, which states that the resultant force ($F_R$) force multiplied by time ($t$) equals the change in the vertical momentum (mass x velocity) of the body.

$$\int F_R \, dt = \Delta mv$$

(2.1)

Rearranging this equation allows the take-off velocity ($v_{to}$) of the CM to be calculated.
\[ v_{t0} = v_i + \frac{\int F_R \, dt}{m} \]  \hspace{1cm} (2.2)

The initial velocity \((v_i)\) equals zero because the jumper began in a stationary standing position, and the final take-off velocity \((v_{t0})\) coincides with the point where the jumper's feet have left the forceplate. The mass \((m)\) was determined as the mass of the subject + the total mass of the hand weights that the jumper held for that trial. In order to calculate the take-off velocity, the combined weight of the subject + hand weights was subtracted from the ground reaction force value on the force-time curve to yield a resultant force \((F_R)\) for every 200th of a second. The resultant force curve was then converted to an acceleration-time graph by dividing through by the combined mass of the subject + weights. This resultant acceleration curve was then integrated with respect to time using Simpson's method for numerical integration to determine the instantaneous velocity of the system's CM.

A second integration with respect to time was performed to calculate the subject's maximum downward displacement during the jump. This was done to examine differences between treatment conditions in the magnitude of upward displacement occurring between the low point and take-off. It was assumed that a greater downward displacement would result in a greater upward displacement, which could impact the magnitude of the average force and duration of the upward jump phase.

The average force was calculated by summing each force value from the point when the jumper was at the low point until take-off and dividing by the number of sampled values in that interval. All force values were normalized to
units of body weight (BW) by dividing the ground reaction forces by the combined weight of the subject + hand weights. This normalization was performed to control for confounding effects that subject mass may have on the take-off velocity.

The actual duration of a jump can be defined as the time interval from the point where the jumper begins the downward movement up until the time when his feet leave the forceplate. However, it is very difficult to determine the exact point where the jumper begins the downward movement because the ground reaction force fluctuates even when someone is standing stationary. Figure 2.1 shows a force-time curve with three different areas underneath it. Area A is the negative impulse, Area B is the positive impulse from the time after Area A to the point where the jumper’s CM is at it’s lowest point, and Area C is the net impulse, which determines the vertical jump performance. Because Areas A and B are equal, they cancel one another and, thus, only the duration of Area C needs to considered for vertical jump performance. As illustrated in Figure 2.1, the duration of the jump for this study was determined by subtracting the time at take-off (e) from the time at which the jumper’s CM was at the lowest point (d).

2.4 STATISTICAL ANALYSIS

The primary statistical analysis compared the effects that CMJ0, CMJ2 and CMJ5 had on the take-off velocity using a one factor repeated measures ANOVA (SPSS for Windows, release:10.0.5). When statistical significance was found for the simple main effects (p≤0.05), post hoc tests were performed. The secondary analysis compared the effects that CMJ0, CMJ2 and CMJ5 had on the
Figure 2.1 – Typical resultant force-time curve illustrating the areas under the curve and the time interval of the jump. The duration is defined as the time at take-off (e) minus the time at which the jumper’s CM is at the lowest point. (d).
duration of the upward jump phase and the average vertical force during the upward jump phase using a one factor repeated measures ANOVA. The secondary analysis was only done if statistical significance was evident in the primary analysis. Hypothesis 1.3.2.1 is based on the theory that an increased take-off velocity with the hand weights is due to an increased duration of the jump and increased average vertical forces. If no relationship existed between the magnitude of the hand weights and take-off velocity, the remaining dependent variables would not be tested.
Chapter Three
RESULTS AND DISCUSSION

3.1 RESULTS

The results for the statistical analyses are presented below. All analyses were completed using $\alpha \leq 0.05$. The means and standard errors for vertical take-off velocity, average force and duration of the upward phase of the jump, and the maximum downward CM displacement are shown in Table 3.1. The peak vertical take-off velocity, and the average force and duration of the upward jump phase for each subject are presented in Appendix D.

3.1.1 Primary Analysis

3.1.1.1 Vertical Take-off Velocity

A one factor repeated measures ANOVA was performed using vertical take-off velocity as the dependent variable. There was an overall significant difference among the three treatment conditions ($F_{(2,60)} = 11.60, p=0.000$). A post-hoc analysis of the simple main effects was performed to examine individual differences between treatment conditions (Appendix E). CMJ2 and CMJ5 were significantly greater than CMJ0 but no significant differences were observed between CMJ2 and CMJ5 (Tables 3.1 and 3.2, and Figure 3.2).
Table 3.1. Means and standard error for vertical take-off velocity ($v_{to}$), average force (avgforce$_{up}$) and duration of the upward phase (time$_{up}$), and the maximum displacement of the CM during the downward movement (downdisplacement) under each treatment condition.

<table>
<thead>
<tr>
<th>Mean ± standard error</th>
<th>CMJ0</th>
<th>CMJ2</th>
<th>CMJ5</th>
</tr>
</thead>
<tbody>
<tr>
<td>vel$_{to}$ (m/s)</td>
<td>2.84 ± 0.42</td>
<td>2.94 ± 0.40*</td>
<td>2.93 ± 0.45*</td>
</tr>
<tr>
<td>avgforce$_{up}$ (BW)</td>
<td>1.92 ± 0.33</td>
<td>1.88 ± 0.33</td>
<td>1.83 ± 0.36*&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>time$_{up}$ (s)</td>
<td>0.33 ± 0.10</td>
<td>0.35 ± 0.12*</td>
<td>0.37 ± 0.14*&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>downdisplacement (m)</td>
<td>-0.324</td>
<td>-0.310</td>
<td>-0.316</td>
</tr>
</tbody>
</table>

N = 31
CMJ0 = Countermovement jump with no hand weight.
CMJ2 = Countermovement jump while holding 2lb hand weight in each hand.
CMJ5 = Countermovement jump while holding 5lb hand weight in each hand.
*: Significant difference from CMJ0 at p ≤ 0.05
a: Significant difference between CMJ2 and CMJ5 at p ≤ 0.05
Table 3.2 ANOVA source table for take-off velocity

<table>
<thead>
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<th>Source</th>
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<th>df</th>
<th>MS</th>
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<th>Sig</th>
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<td>Between Groups</td>
<td>0.160</td>
<td>2</td>
<td>0.080</td>
<td>11.60</td>
<td>0.000</td>
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<tr>
<td>Within Groups</td>
<td>5.04</td>
<td>90</td>
<td></td>
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<tr>
<td>Error</td>
<td>0.41</td>
<td>60</td>
<td>0.007</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subjects</td>
<td>4.62</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>10.24</td>
<td>182</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.1 Graph of the means for take-off velocity under each treatment condition (CMJ0, CMJ2 and CMJ5).
3.1.2 Secondary Analysis

The first two hypotheses in this study are based on the theory that increased take-off velocity with hand weights is due to an increased average force and duration of the upward phase of the jump. Because significant differences in take-off velocity were found between treatment conditions during the primary analysis, secondary analyses were conducted to gain insight into whether the improved take-off velocity was due to an increase in the applied average force, or due to an increase in the duration of the upward phase, or possibly an increase in both.

3.1.2.1 Average Force during the Upward Phase

A one factor repeated measures ANOVA was performed using average force of the upward movement as the dependent variable (Table 3.3 and Figure 3.2). There was an overall significant difference among the three treatment conditions \((F(2,60) = 8.73, p= 0.001)\). A post-hoc analysis of the simple main effects was performed to examine individual differences between treatment conditions (Appendix E). Results indicate that the average force of the upward phase of the jump during CMJ5 was significantly lower than CMJ0 and CMJ2, but no other significant differences were observed between the treatment conditions.

3.1.2.2 Duration of the Upward Phase

A one factor repeated measures ANOVA was performed using the duration of the upward phase as the dependent variable (Table 3.4 and Figure 3.3). There was an overall significant difference among the three treatment conditions \((F(2,60) = 16.79, p= 0.000)\). A post-hoc analysis of the simple main
effects was performed to examine individual differences between treatment conditions (Appendix E). Results indicate that the duration of the upward phase of the jump for CMJ2 and CMJ5 was significantly greater than CMJ0 and that CMJ5 was significantly greater than CMJ2.
Table 3.3 ANOVA source table for average force of the upward phase.

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>0.105</td>
<td>2</td>
<td>0.052</td>
<td>8.73</td>
<td>0.001</td>
</tr>
<tr>
<td>Within Groups</td>
<td>3.263</td>
<td>90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>0.360</td>
<td>60</td>
<td>0.006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subjects</td>
<td>2.903</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>6.630</td>
<td>182</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.2 Graph of the means for average force during the upward phase under each treatment condition (CMJ0, CMJ2 and CMJ5).
Table 3.4 ANOVA source table for the duration of the upward phase

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>0.033</td>
<td>2</td>
<td>0.016</td>
<td>16.79</td>
<td>0.000</td>
</tr>
<tr>
<td>Within Groups</td>
<td>0.405</td>
<td>90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>0.058</td>
<td>60</td>
<td>0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subjects</td>
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<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0.843</td>
<td>182</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.3 Graphs of the means for the duration of the upward phase of the jump (d-e in Figure 2.1) under each treatment condition (CMJ0, CMJ2 and CMJ5).
3.2 DISCUSSION

The purpose of this study was to determine the effect that 2lb and 5lb hand weights have on the vertical take-off velocity of a CMJ with an arm-swing. In addition, the average force and duration of the upward movement were examined in a secondary analysis to provide insight into the mechanism associated with the hypothesized improved performance. The primary analysis indicated that vertical take-off velocity and thus, jump height, was significantly greater when performing a CMJ using 2lb hand weights (CMJ2) and 5lb hand weights (CMJ5) compared to no weight (CMJ0). These results also showed that the take-off velocities between the 5lb and 2lb hand weights were not significantly different from one another. The secondary analysis indicated that the duration of the upward phase was significantly greater when using 2lb and 5lb hand weights but that the average force during the upward phase was significantly lower with the addition of 2lb and 5lb hand weights.

The mean vertical take-off velocity of 2.84 m/s for CMJ0 was slightly higher than other studies in which subjects performed a CMJ with an arm-swing. Past research has reported take-off velocity means of 2.29 m/s (Shetty and Etnyre, 1989), 2.61 m/s (Harman et al., 1990) and 2.75 m/s (Feltner et al., 1999). These differences are likely due to the subject population being tested. In the present study 12 of the 31 subjects participated on a varsity volleyball team and were likely more skilled at performing the jumps. The previous studies indicated that the subjects were from a general university population and, therefore, may not have had the high percentage of skilled jumpers participating in their study.
In the first two hypotheses it was theorized that 2lb and 5lb hand weights would increase the take-off velocity of a CMJ with an arm-swing (Hypothesis 1.3.2.1) and that there would be a greater increase in take-off velocity with the 5lb hand weights compared to the 2lb hand weights (Hypothesis 1.3.2.2). The results supported Hypothesis 1.3.2.1 in that CMJ2 and CMJ5 produced greater take-off velocities than CMJ0. However, Hypothesis 1.3.2.2 was not supported as CMJ5 did not produce higher take-off velocities than CMJ2.

A possible explanation for the fact that CMJ5 did not produce greater take of velocities than CMJ2 is presented in Figure 3.4. This graph illustrates a hypothetical range of take-off velocities determined by a varying amount of hand weight. The take-off velocity values for 0lbs (2.84 m/s), 2lbs (2.94 m/s) and 5lbs (2.93 m/s) are based on the results of the present study and the remaining weights are linked with hypothetical predictions. The graph shows that an increase in the amount of hand weight causes a steady gain in take-off velocity over and above 2.84 m/s until a peak velocity occurs at 4lbs. The values then progressively decrease from 5 to 6lbs but still remain above 2.85 m/s. At 7lbs, there is no longer a gain in take-off velocity because the weight is too heavy and the jumper is no longer inside the weight range to produce gains in jump height. This graph implies that there is an optimal range of hand weight that allows for gains in jump height and that the 2lb and 5lb hand weights fall within that range. It can therefore be theorized that CMJ5 did not produce greater gains in take-off velocities than CMJ2 because the 5lb hand weight was nearing the end of the optimal range and the trade-off between additional mass and take-off velocity was no longer optimal.
Figure 3.4 Graph illustrating a hypothetical range of hand weights that produce varying take-off velocities. The values for 0lb, 2lb and 5lb hand weights are based on the present study.
The third hypothesis stated that the duration of the upward phase would be increased with the addition of 2lb and 5lb hand weights. This hypothesis was supported since the 2lb and 5lb hand weights both exhibited significantly greater durations throughout the upward movement than the jumps without weight. Because the magnitude of maximum downward displacement was similar between the three conditions (Table 3.1), it can be assumed that the magnitude of upward displacement was also similar. Therefore, a greater duration due to increased displacement from the low point of the jump to take-off can be ruled out. These findings substantiate the theory that the hand weight slowed the arm velocity, which resulted in a longer time to complete the upward movement of the jump.

The fourth hypothesis stated that the average force throughout the upward jump phase would increase with 2lb and 5lb hand weights. This hypothesis was not supported because the average force actually decreased during CMJ2 and CMJ5. Although statistical significance was only evident between CMJ0 and CMJ5, the mean average force progressively decreased as the weight increased. Even though it is concluded that the greater take-off velocities during CMJ2 and CMJ5 are primarily due to the increase in time, the factors contributing to the decreased average force are now examined.

One possibility for the lower average force may simply be the greater length of time it took to perform the jumps. It is possible that the subjects produced force profiles during the weighted jumping performances that showed a greater length of time spent during low force output stages that unduly weighted these intervals during the averaging process.
When examining the downward movement, it was thought that the hand weights during the back swing would load the muscles eccentrically and allow for greater forces at the start of the upward movement. These higher starting forces would then enhance the potential for a greater net impulse and average force to be produced (Walshe, Wilson and Ettema, 1998). Although the back swing with the hand weight may have loaded the muscles eccentrically, it may have also slowed the downward movement of the CM. Due to the force-velocity properties of an eccentric muscle contraction, whereby greater forces are produced at higher speeds of muscle lengthening, a reduction in CM velocity would produce decreased forces. As a result, the benefits achieved from eccentric loading would have been partially lost.

When examining the upward phase of the jump it was hypothesized that a greater reactive force at the shoulder would occur with the addition of hand weights when the arms were swinging forward and upward. In turn, this would create a larger torque acting against the upward movement of the trunk, resulting in a slower concentric contraction and, consequently, greater hip extensor force. Although a slower contraction of the hip extensors may have occurred, the amount of force contribution may have been offset by a couple of factors. One of the reasons for decreased force may stem from the properties of the stretch-shorten cycle (SSC). Research has shown that any delay between the eccentric and concentric contraction in an SSC movement decreases the force at the onset of the concentric phase as well as the maximum force (Aura and Komi, 1986; Wilson, Elliott and Wood, 1990). In order to maximize the force during the concentric contraction of an SSC movement, it is necessary to minimize the
delay between the eccentric and concentric phases and ensure that the transitional forces are maximized by decelerating rapidly and as close to the turnaround point as possible (Walshe et al., 1998). In this study, it may have taken longer for the hip and knee extensors to transit from the downward to upward phase during the weighted conditions due to the slower arm velocity and higher reactive shoulder forces acting against the upward movement of the CM. Therefore, the benefits that would be gained from the SSC properties during CMJ0 would have been dissipated during the weighted conditions.

Another possibility for the lower force production is that the coordination of segments may have been altered during the weighted condition. There are a number of theories regarding the pattern of segmental coordination. One of these theories states that a simultaneous pattern occurs during the movement where all segments initiate extension at the same time (Kreigbaum and Barthels, 1981). Hudson (1986) substantiated this theory of multisegmental simultaneity when examining skilled and unskilled jumpers and she further concluded that producing very small delays between adjacent segments was more critical than the actual sequencing of segments. Munkasy and McNitt-Gray (1998) compared differences in coordination between jumps with an arm-swing and jumps without an arm-swing. They found that six of the ten subjects who performed the arm-swing jumps did not exhibit a multisegmental simultaneity, whereas all the jumpers who performed jumps without an arm-swing exhibited some multisegmental simultaneity. They concluded that the arm-swing compromised simultaneity of multiple segments. Although there is no video-based coordinate data to examine segmental coordination in the present study, it can be theorized
that the weighted jumps may have interrupted the coordination or simultaneity that would normally be present. For example, a slow transition from the back swing to forward swing with the weights may have allowed the trunk to produce a greater upward angular displacement before the arms were in a position to produce large opposing torques at the trunk. This means that the hip extensors would not have experienced slowed contractions as much as during the unweighted conditions. As a result, less force would be produced due to the concentric force-velocity properties of the muscle. Further research using video-based coordinate data is required to determine the exact changes that take place in the segmental coordination of weighted jumps.

There are a few limitations to the interpretation and generalization of the results of this study. Although these results can be generalized to all male athletes between the ages of 18 and 30, it should be noted that almost half of the subjects were from the University of Manitoba volleyball team. Volleyball players are often involved in intense training programs to improve vertical jump height and, as such, this population is regarded as having one of the highest vertical jump heights among all athletic populations (Sawula, 1991). Therefore, they were likely accustomed to performing the type of jump requested of them in this study and may have found it easier to transfer the task of jumping without weight to learning how to jump with hand weights. In addition, less practice time may have been required to become familiar with the weights for the skilled jumpers. The recreation hockey players, on the other hand, may have found it more difficult to control the heavier weight because they may not have been accustomed to performing a CMJ, and adding weight may have made it even
more cumbersome. Subjects were given practice time to become familiar with the hand weights but this task is not something that is performed very often and the addition of hand weights for some subjects may have actually hindered performance as opposed to improving jump height. This may explain why some subjects did not produce any gains in jump height with the hand weight. A consideration for future research would be to allow more practice time or include a number of practice sessions before testing.

Another limitation stems from the fact that a fixed amount of weight was used, regardless of the jumper's weight and strength. It can be assumed that individuals with varying levels of size and strength would produce different take-off velocities at the same load. For example, a jumper with less arm strength may have found the 5lb weight too heavy, which may have resulted in a decreased arm velocity to the point where the trade-off between mass and velocity was too great to produce gains in jump height. Conversely, a stronger individual may have produced peak jump heights with the 5lb weight. This means that the optimal range for take-off velocity may be different from one person to the next and it should not be assumed that the same amount of weight will produce the same gains in take-off velocity for every individual. Possible considerations for future research may be to determine a jumper's optimal weight using a certain percentage of the jumper's body weight or arm strength. This would allow one to gain insight into the exact amount of weight required for every individual and overcome this limitation of the study.

Although the results of this study indicate that statistical significance was evident between the weighted conditions one might question whether a 3.16%
increase from 2.84 m/s to 2.94 m/s would equate to large gains in CM upward displacement. If the gain in vertical displacement is very small then it may not be practical for athletes, coaches and trainers to apply these results in a practice or competitive setting. Using equation 1.4, an increase in take-off velocity of 0.09 m/s yields an increase of approximately 3 cm of CM displacement. Even though this amount appears small, it potentially could have a large impact during competitive sports when small increases in jump height are vital to the outcome of the competition.

These results have a number of implications for athletes, coaches, researchers, and trainers. By supporting the theory that hand weights can improve jump height, a method of training using hand weights can be adopted to aid in improving one’s peak jump performance. Training with hand weights allows the movement to be as sport specific as possible, which means that greater gains are likely because the jumper is performing the task as close to the actual movement as possible. One advantage from a coach’s point of view is that hand weights may be incorporated into a practice setting. For example, attaching a weight to the wrist may allow athletes to be involved with a regular practice routine while using the weight to improve jump height. Further study that involves finding one’s optimal hand weight and training using this method is required to determine if coaches and athletes should be incorporating hand weight jumps in the training regimen.

These results also show the potential benefits that an increase in arm strength has on the vertical jump height. A jumper with heavier, stronger arms may be at an advantage versus a jumper with smaller arms. If stronger arms lead
to greater jump height than strength training the arms when involved in a program to improve vertical height may be required.
4.1 SUMMARY

In many sports the vertical jump is a necessary skill, and utilizing it to its full potential may make the difference in winning at a competitive level. Trainers, coaches and researchers have studied the vertical jump extensively at a neuromuscular and biomechanical level to determine the factors necessary for maximal jump height and to discover the best methods in training the body for optimal jump performance.

In order to produce optimal jump heights, a jumper must generate a greater net impulse, which occurs during the upward movement of a CMJ. A greater net impulse means that an increased force, duration, or a combination of both has been enhanced. One way to manipulate these variables is to add a hand weight to the jumper. Although it appears counterintuitive to add weight to increase jump height, an optimal amount of hand weight has the potential to increase the time of the jump while sustaining high forces, thus allowing the net impulse and jump height to increase.

The results of the present study reveal that adding a 2lb and 5lb hand weight can improve one’s ability to jump higher when performing a CMJ with an arm-swing. Furthermore, these weights may fall into an optimal range of hand
weight that allows for increases in take-off velocity. This range is likely to change from one person to the next, depending on the size and strength of the individual and the ability to control the weights.

The results also show that jumping with hand weights increases the duration of the jump but has little effect on the average force of the upward jump phase. Although average forces significantly decreased in this study between CMJ0 and CMJ5, the differences were small and the need for sustaining high forces during the upward phase is still necessary for optimizing jump height.

There are currently no studies to date that have examined the effects of hand held weights on take-off velocity during a CMJ. The implications of the results support a need for further research regarding training with hand weights and including an arm-strengthening component to a vertical jump training regimen.

4.2 CONCLUSIONS

4.2.1 Within the limitations and assumptions previously stated, vertical take-off velocity was increased using hand weights (hypothesis 1.3.2.1 supported) and the duration of the upward phase was increased with the addition of hand weights (hypothesis 1.3.2.3 supported).

4.2.2 Within the limitations and assumptions previously stated, 5 lb hand weights were not more effective in increasing take-off velocity than 2 lb hand weights (hypotheses 1.3.2.2 not supported), and the average force during the upward jump phase
was not increased with the addition of hand weights (hypothesis
1.3.2.4 not supported).

4.3 RECOMMENDATIONS FOR FUTURE RESEARCH

Research should be completed to further define and describe the effects of
hand held weight on take-off velocity in order to:

4.3.1 Determine an optimal weight for every individual as a percentage
of body weight or arm strength.

4.3.2 Examine the effects of a training program using hand weights.

4.3.3 Compare the present jumping method to a squat jump with an
arm-swing while holding onto a hand weight.

4.3.4 Examine differences in vertical jump height following an arm
strengthening program.

4.3.5 Determine the timing of the movement of body segments using
video coordinate data.
REFERENCES


66

APPENDIX A

ETHICAL APPROVAL
Certificate of Approval

PRINCIPAL INVESTIGATOR
Eric Sprigings (R. Dueck)

DEPARTMENT
Kinesiology

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT
College of Kinesiology
University of Saskatchewan

CO-INVESTIGATORS

SPONSORING AGENCIES
None

TITLE:
Effect of Handweights in a Countermovement Jump Between Skilled and Unskilled Jumpers

APPROVAL DATE
July 16, 1999

TERM (YEARS)
3

AMENDED:

MODIFICATION OF:

CERTIFICATION:
The protocol and consent form (if applicable) for the above-named project have been reviewed by the Committee and the experimental procedures were found to be acceptable on ethical grounds for research involving human subjects.

APPROVED.

D.W. Quest, Chair
University Advisory Committee on Ethics in Human Experimentation

This Certificate of Approval is valid for the above term provided there is no change in experimental procedures, subject to annual re-approval.

Please send all correspondence to:
Office of Research Services
University of Saskatchewan
Room 210 Kirk Hall, 117 Science Place
Saskatoon, SK S7N 5C8
Phone: (306) 966-4633 Fax: (306) 966-8597
APPENDIX B

COVER LETTER AND CONSENT FORM
Dear Athlete,

The purpose of this study is to examine the effects of hand-held weights on the vertical jump. You will be required to attend the laboratory on one occasion lasting 35-45 minutes. You will perform approximately 12-15 countermovement jumps on a force platform, where you will start from a standing position and make a downward movement with your legs before pushing off from the ground. Every jump will be performed with an armswing. To minimize backward or forward movement during the jump, you will attempt to land as close as possible to your take-off point on the floor.

Upon arrival, you will perform stretching exercises to warm-up. Following this, a minimum of six practice jumps will be performed on the force platform. You must perform at least two practice jumps while holding a weight of 2 lbs in each hand, two with a 5 lb weight in each hand and two without any weight. After performing at least six jumps you may continue to practice until you feel comfortable with the procedure.

After the practice jumps you will perform nine countermovement jumps on a force platform. Three jumps will be performed while holding a weight of 2 lbs in each hand, three with a 5 lb weight in each hand and three without any weight. There will be a minimum two-minute rest period in between each jump.

If you choose to participate you may withdraw from the study at any time without fear of penalty. All individual results are confidential and will not be seen by the research team. Your identity will not be revealed and the final report will summarize the group results. The findings will be made available to you upon your request at the end of the project.
YOUR STATEMENT OF CONSENT

Title of Project:

Effect of Hand Held-Weights on Take-off Velocity in a Countermovement Jump

Investigators: E.J. Sprigings, Ph.D., (966-6481) & R.G. Dueck B.Sc (452-0788)

I have received explanation about the nature of the study, its purpose and procedures. I understand what my participation will involve.

I am a volunteer and can withdraw at any time from the study without fear of penalty.

I understand that I will be required to attend the laboratory on one occasion for approximately 35-45 minutes

I will be required to perform approximately 12-15 countermovement jumps on a force platform including warm-up jumps, and jumps while holding handheld weight of up to five pounds.

Muscle soreness may occur after testing due to repeated jumping.

The individual data that I provide will remain confidential from sources outside of the study. My identity will not be revealed in reports or research publications.

I will receive a summary of the project, upon request, following the completion of the project.

Signature of Participant ___________________________ Date __________

Signature of Witness _______________________________ Date __________

Signature of Investigator ___________________________ Date __________
APPENDIX C

FORTRAN SOURCE CODE FOR CALCULATING TAKE-OFF VELOCITY, AVERAGE FORCE AND DURATION OF THE UPWARD JUMP PHASE
This version computes the global maximum downward displacement used by the jumpers during their counter movement. This version outputs the duration of the jump take-off, as well as normalizes the force to the subject's body weight.

NAME: DUECKM4.FOR
LAST ALTERED July 30, 2002
PROGRAMMER: E. SPRIGINGS

THE FOLLOWING PROGRAM CALCULATES:
A) THE INSTANTANEOUS FORCE ON THE FEET AT THE LOWEST POINT OF THE COUNTER-MOVEMENT JUMP.
B) THE MAXIMUM DOWNWARD ACCELERATION.
C) THE MAXIMUM DOWNWARD VELOCITY.
D) THE PEAK GROUND REACTION FORCE DURING THE TAKE-OFF PORTION OF THE JUMP.
E) THE TAKE-OFF VELOCITY.
F) THE HIGHEST POWER GENERATED PRIOR TO TAKE-OFF.
G) MAXIMUM DOWNWARD DISPLACEMENT OF CM.

IT IS ASSUMED THAT THE PERSON IS STANDING STATIONARY ON THE PLATFORM AT THE START OF DATA COLLECTION, AND THAT THE SUBJECT'S FEET LEAVE THE PLATFORM DURING THE JUMP.

NOTE: BECAUSE THE FORCE PLATFORM IS NOT CALIBRATING CORRECTLY IN THE VERTICAL DIRECTION, THIS PROGRAM ADJUSTS THE FORCE VALUES INTERNALLY IN THE PROGRAM BY USING THE SUBJECT'S BODY WEIGHT WHILE STANDING MOTIONLESS. (UNLIKE VJUMP3.FOR, THE SUBJECT'S MASS MUST BE ENTERED INTO THE PROGRAM.)

* NETIMP(2000),DISPY(2000),MAXDOWNWARD_DISP
CHARACTER*10 NAME1
NDATA=0
WRITE(*,2)
2 FORMAT(/,' ENTER THE NAME OF THE DATA FILE THAT YOU WISH',/,
'* TO DETERMINE THE VERTICAL PEAK POWER FOR!',/,
'* (Note: there must be at least 0.1 s of data in the file)',/)
READ(*,4)NAME1
4 FORMAT (A10)
WRITE(*,5)
5 FORMAT(/,' ENTER THE MASS OF THE SUBJECT!',/)
READ(*,6) MASS
WRITE(*,6)
6 FORMAT(/,' ENTER THE SAMPLING RATE OF YOUR DATA COLLECTION!',/)
READ(*,7) SR
DT=1.0/3
WRITE(*,7)
7 FORMAT(/,' ENTER THE "ZERO" THRESHOLD VALUE!',/)
READ(*,*) THRESH
OPEN (UNIT=20, FILE=NAME1)
OPEN (UNIT=21, FILE='POWER.OUT')
OPEN (UNIT=22, FILE='VELOCITY.OUT')
OPEN (UNIT=23, FILE='NETIMP.OUT')
OPEN (UNIT=24, FILE='FORCE.OUT')
DO 101 I=1,2000
READ(20,*) JUNK1,Y(I)
IF (Y(I) .LE. THRESH) GOTO 103 ! ends data collection when subject leaves the plate.
END
NDATA=NDATA+1
101 CONTINUE

C THE FOLLOWING SCALES THE FORCE VALUES ACCORDING TO THE SUBJECT'S
C KNOWN BODY WEIGHT.
103 SUM=0.0
   DO 505 J=1,1NT(SR*.1)
     SUM=SUM+Y(J)
   505 CONTINUE
   AVG=SUM/(SR*.1) ! first 0.1 s of data are averaged while the subject is
                  ! motionless to determine the force plate output for
                  ! body weight.
   SF=(MASS*9.81)/AVG ! this scaling factor is now used to multiply
                      ! the raw force plate values to convert them
                      ! to true Newtons of force.
   DO 506 K=1,NDATA
     Y(K)=Y(K)*SF
   506 CONTINUE
   SumF=0
   Count=0
   FLAG=0
   FMAX=0.0
   FMIN=1000.0
   VELNMX=0.0
   DISPMIN=0.0
   FNEGMAX=MASS*9.81
   DO 102 I=1,NDATA
     F(I)=Y(I)
     NDATA2=I
   CALL INTEG(NDATA2,DT,F,AREA)
   DO 102 I=1,NDATA
     F(I)=Y(I)
     NDATA2=I
   CALL INTEG(NDATA2,DT,F,AREA)
   C THE FOLLOWING SUBTRACTS THE GRAVITATIONAL IMPULSE FROM THE FORCE PLATE
   C IMPULSE DURING THE SAME TIME INTERVAL.
   NETIMP(I) = AREA - (MASS*9.81*DT*(I-1))
   VELY(I)=NETIMP(I)/MASS
   C THE FOLLOWING COMPUTES THE DISPLACEMENT OF THE CG DURING THE JUMP.
   CALL INTEG(NDATA2,DT,VELY,AREA)
   DISPY(I) = AREA     ! DISPLACEMENT IN METERS
   IF (DISPY(I) .LT. DISPMIN) THEN
     DISPMIN = DISPY(I)
   ENDF
   C THE FOLLOWING COMPUTES THE INSTANTANEOUS POWER FOR THE CURRENT TIME
   C STEP.
   POWER(I)=VELY(I)*F(I)
   TEMP=POWER(I)
   IF (TEMP .GT. BESTPOW) BESTPOW=TEMP
   IF (VELY(I).LT.-0.2) FLAG=1 ! identifies start of downward phase.
   IF (FLAG.EQ.1 .AND. VELY(I).GE.0.0) THEN
     FLAG=0
   FSQUAT=Y(I) ! picks off peak ground reaction force at max. squat
   ndata3=i-1
MAXDOWNWARD_DISP= DISPY(I)
time_squat = dt*i-dt

Do 605 J=I,Ndata ! This section works out avg force
SumF=SumF+Y(J) ! from max squat to the point of takeoff.
Count=Count+1
605 Continue
AvgF=SumF/Count
AvgBW=AvgF/(Mass*9.81) ! converts to multiples of body weight
ENDIF ! squat position.

IF (Y(I) .LT. FNEGMX .AND. FLAG .EQ. 1) THEN
FNEGMX=Y(I)
ACCELN=(Y(I)-MASS*9.81)/MASS ! picks off max. neg accel. during
ENDIF ! downward movement phase.

IF (VELY(I) .LT. VELNMX .AND. FLAG .EQ. 1) VELNMX=VELY(I)
! picks off max. downward velocity.

IF (Y(I).GT.FMAX) FMAX=Y(I) ! picks off peak ground reaction force ! during take-off.

C IF (Y(I).LT.FMIN .AND. FLAG .EQ. 1) THEN ! picks off minimum ground
C FMIN = Y(I) ! reaction force during
C NSTART = I ! the counter-movement.
C ENDIF

VFINAL=VELY(I) ! captures the take-off velocity.

102 CONTINUE

C DURATION = (NDATA-NSTART)*DT
DURATION = COUNT*DT ! from max. squat to takeoff

WRITE(*,1111) DURATION
1111 FORMAT(/,' DURATION (MAX. SQUAT to TAKEOFF) =', F8.3,' sec.')
C WRITE(*,*)' NSTART (sample #) = ', NSTART
C WRITE(*,*)' NSTART (time) = ', NSTART*dt-dt

C WRITE(*,*)' NDATA (sample #) = ', NDATA
C WRITE(*,*)' NDATA (time) = ', NDATA*dt-dt

C WRITE(*,*)' MINIMUM FORCE = ', FMIN

WRITE(*,10) BESTPOW
10 FORMAT(/,' THE HIGHEST POWER GENERATED PRIOR TO TAKE-OFF IS:','*','F8.2',' WATTS')

C ******************NEW OUTPUT*********************************
WRITE(*,110) FSQUAT,ndata3*dt
110 FORMAT(/,' THE GROUND REACTION FORCE AT MAX. SQUAT IS:','F8.2, *' NEWTONS','/ the corresponding time value is:','F8.3)

WRITE(*,111) FMAX
111 FORMAT(/,' THE PEAK GROUND REACTION FORCE GENERATED PRIOR',
  *' TO TAKE-OFF IS:',F8.2,
  *' NEWTONS')

WRITE(*,113) AvgBW
113 FORMAT(/,' THE AVERAGE GROUND REACTION FORCE (x BW) GENERATED ',
  *' FROM MAX. SQUAT TO TAKE-OFF IS:',F8.2, 2x,' (x body weight)')

WRITE(*,112) VFINAL
112 FORMAT(/,' THE FINAL TAKE-OFF VELOCITY AT TAKE-OFF IS:',F8.2,
  *' M/S')

WRITE(*,1110) VELNMX
1110 FORMAT(/,' THE MAXIMUM DOWNWARD VELOCITY IS:',F8.2,
  *' M/S')

C WRITE(*,1112) ACCELN
C 1112 FORMAT(/,' THE MAXIMUM DOWNWARD ACCELERATION IS:',F8.2,
C  *' M/S/S')

WRITE(*,1112) DISPMIN
1112 FORMAT(/,' THE GLOBAL MAXIMUM DOWNWARD DISPLACEMENT IS:',F8.2,
  *' M')

WRITE(*,1113) MAXDOWNWARD_DISP, time_squat
1113 FORMAT(/,' THE MAXIMUM DOWNWARD DISPLACEMENT IS:',F8.2,
  *' M',/,' (the time corresponding with max squat is:',F8.3,
  *' S'),/)

C *******************************************END OF NEW OUTPUT*******************************************

DO 300 I=1,NDATA
  WRITE(21,11) I*dt-dt,POWER(I)
11 FORMAT(F5.3,2X,F8.2)

DO 301 I=1,NDATA
  WRITE(22,11) I*dt-dt,VELY(I)
301 CONTINUE

DO 303 I=1,NDATA
  WRITE(23,11) I*dt-dt,NETIMP(I)
303 CONTINUE

DO 304 I=1,NDATA
  WRITE(24,11) I*dt-dt,F(I)/(Mass*9.81)
304 CONTINUE

CLOSE (UNIT=20)
CLOSE (UNIT=21)
CLOSE (UNIT=22)
CLOSE (UNIT=23)
STOP
END

C *******************************************************END OF NEW OUTPUT*****************************************************
SUBROUTINE INTEG(NDATA2, DT, Y, AREA)
DIMENSION Y(2000)

C THE FOLLOWING SETS UP THE INTERVAL OF THE "Y" HISTORY VALUES THAT YOU WANT TO INTEGRATE.
C
C THE FOLLOWING CHECKS TO SEE IF THE NUMBER OF FORCE VALUES (I.E. INTERVALS OF TIME) IS EVEN OR ODD.
C THE FIRST FRAME ANALYSED IS CONSIDERED TO OCCUR AT ZERO TIME.
C IF THE NUMBER OF FORCE VALUES ANALYSED IS ODD, THEN THE NUMBER OF INTERVALS WILL BE EVEN AND SIMPSON'S RULE CAN BE USED. IF THE NUMBER OF FORCE VALUES ANALYSED IS EVEN (WHICH MEANS THE NUMBER OF INTERVALS WILL BE ODD) THEN THE TRAPEZOIDAL METHOD WILL HAVE TO BE USED FOR THE LAST INTERVAL AND ITS VALUE ADDED ON TO THE VALUE COMPUTED BY SIMPSON'S METHOD ON (N-1) POINTS.

A=NDATA2/2.0
B=INT(NDATA2/2.0)
IF(A.NE.B) GO TO 2

C CALCULATING AREA OF LAST INTERVAL FOR ODD NUMBER OF INTERVALS.(I.E. EVEN NUMBER OF FRAMES)
AREAN=DT*(Y(NDATA2)+Y(NDATA2-1))/2
NDATA2=NDATA2-1
GO TO 2

C SEE P.28 "LABORATORY COURSE IN PHYSICAL CHEMISTRY" FOR SIMPSON'S METHOD EQUATION.
C
C THE FOLLOWING CALCULATES THE SUM OF THE ODD INTERVAL "Y" VALUES.
2 SUMO=0.0
DO 4 I=2, (NDATA2-1), 2
SUMO=SUMO+Y(I)
4 CONTINUE
C
C THE FOLLOWING CALCULATES THE SUM OF THE EVEN INTERVAL "Y" VALUES.
SUME=0.0
DO 6 I=3, (NDATA2-2), 2
SUME=SUME+Y(I)
6 CONTINUE
AREA=DT/3.0*(Y(1)+Y(NDATA2)+(4*SUMO)+(2*SUME))
IF(A.NE.B) GO TO 10
AREA=AREA+AREAN
10 RETURN
END
APPENDIX D

VERTICAL TAKE-OFF VELOCITY, DURATION AND AVERAGE FORCE OF THE UPWARD JUMP PHASE FOR EACH SUBJECT
Vertical Take-off Velocity (vel\(_{to}\)), Duration of the Upward Jump Phase (time\(_{up}\)) and Average Force During the Upward Jump Phase (avgforce\(_{up}\)) for Every Subject Under Each Treatment Condition.

<table>
<thead>
<tr>
<th>Subject</th>
<th>vel(_{to}) (m/s)</th>
<th>time(_{up}) (s)</th>
<th>avgforce(_{up}) (BW)</th>
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<tbody>
<tr>
<td></td>
<td>CMJ0</td>
<td>CMJ2</td>
<td>CMJ5</td>
</tr>
<tr>
<td>1</td>
<td>2.93</td>
<td>3.16</td>
<td>2.98</td>
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<tr>
<td>2</td>
<td>3.01</td>
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</tr>
<tr>
<td>4</td>
<td>2.91</td>
<td>2.98</td>
<td>3.11</td>
</tr>
<tr>
<td>5</td>
<td>3.03</td>
<td>3.03</td>
<td>3.04</td>
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<tr>
<td>6</td>
<td>3.28</td>
<td>3.37</td>
<td>3.70</td>
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<tr>
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<td>3.17</td>
<td>3.23</td>
<td>3.30</td>
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<td>8</td>
<td>3.11</td>
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<td>3.15</td>
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<td>2.69</td>
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<td>2.78</td>
<td>2.72</td>
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<tr>
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<tr>
<td>31</td>
<td>2.81</td>
<td>2.81</td>
<td>2.87</td>
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</table>

CMJ0 = Countermovement jump with no hand weight.
CMJ2 = Countermovement jump while holding 2lb hand weight in each hand.
CMJ5 = Countermovement jump while holding 5lb hand weight in each hand.
APPENDIX E

POST HOC ANALYSES USING SIMPLE MAIN EFFECTS
Simple Main Effects for Vertical Take-off Velocity.

<table>
<thead>
<tr>
<th>Treatment Condition</th>
<th>Treatment Condition</th>
<th>Significance</th>
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<tr>
<td></td>
<td>CMJ5</td>
<td>0.001</td>
</tr>
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<td>CMJ2</td>
<td>CMJ0</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>CMJ5</td>
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<tr>
<td>CMJ5</td>
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<tr>
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<td>CMJ2</td>
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</table>

Simple Main Effects for Average Force During the Upward Jump Phase.

<table>
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Simple Main Effects for Duration of the Upward Jump Phase.

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