THE EFFECT OF CUES ON VERTICAL JUMP PERFORMANCE

By
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A Thesis
Submitted To
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ABSTRACT

Vertical jumping ability is an important determinant of success in various competitive and recreational athletic activities. Coaches frequently use verbal cues (e.g., explode) to indirectly change the movement pattern or coordination strategy of an athlete's vertical jump, with the belief that performance can be enhanced (Orlick, 1986; Jones et al., 1988). However, there is a paucity of research to support this notion. The primary objective of this study was to determine if cues can change CMJ technique, and secondarily to determine if cues can change CMJ height. METHODS: Data was collected from 36 volunteer male subjects between the ages of 18 and 35. On a single occasion, each subject performed a standardized countermovement jump protocol under 4 different conditions. A 'Non-cued' (NC) condition was performed both before and after the cued conditions. Three cued conditions *(Down Fast (DDF), Explode From Bottom (EFB), Push-off Toes (POT))* were performed in a randomized, cross-over fashion. For each condition, subjects performed three consecutive jumps with 45-60 seconds rest between jumps and 2-3 minutes between conditions. Ground reaction forces were recorded using an instrumented force platform. Acceleration, velocity, displacement and impulse profiles were calculated based on the force-time data collected. All jumps performed in this study were maximal countermovement jumps performed with hands on hips at all times. RESULTS: The cues DDF and EFB had significant effects on 12 and 5 of the 14 dynamic jump variables, respectively. In contrast, the cue POT did not have a significant effect on any of the 14 dynamic jump variables. Jump height was not significantly affected by any of the cues, compared to the non-cued condition. CONCLUSION: The results of this study indicate that some of the dynamic variables for the DDF and EFB conditions were significantly different from the non-cued condition. The differences in dynamic variables caused by the cues DDF and EFB demonstrate a change in jump technique. Despite changes in jump technique, the results showed that jump height did not change when the non-cued condition was compared to the cued conditions.

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DEFINITIONS

Acceleration	The rate of change in velocity (Hall, 1995)
Biomechanics	Application of mechanical principles in the study of living organisms (Hall, 1995)
Center of mass	The point around which the mass and weight of a body are balanced in all directions (Hall, 1995)
Concentric	Contraction involving shortening of a muscle (Hall, 1995)
Cue	A signal (as a word, phrase, or bit of stage business) to a performer to begin a specific speech or action (Merriam-Webster dictionary)
Displacement	Change in position (Hall, 1995)
Dynamics	Branch of mechanics dealing with systems subject to acceleration (Hall, 1995) Kinematics and kinetics are subdivisioins of dynamics (Hall, 1995)
Eccentric	Contraction involving lengthening of a muscle (Hall, 1995)
Force	Push or pull; the product of mass and acceleration (Hall, 1995)
Goniometer	An instrument used to measure joint angles
Impulse	Product of force and the time over which the force acts (Hall, 1995)
Instructions	1) direction or order (Oxford dictionary) 2) detailed directions on procedure (www.yourdictionary.com) 3) advice and information about how to do or use something, often written in a small book or on the side of a container (Cambridge dictionary)
Kinematics	The form, pattern, or sequencing of movement with respect to time (Hall, 1995)
Kinetic energy	Capacity to do work by virtue of a body's motion = $\frac{1}{2}mv^2$ (Hall, 1995)

Kinetics	Study of the action of forces (Hall, 1995)
Lift-off	The instant immediately prior to toe-off where the ground reaction force (GRF) falls below the bodyweight of the jumper.
Momentum	Product of a body's mass and its velocity (Hall, 1995)
Potential energy	Capacity to do work by virtue of a body's position = mgh (Hall, 1995)
Power	Rate of work production that is calculated as work divided by the time during which the work was done (Hall, 1995)
Projectile	A body in free fall that is subject only to the forces of gravity and air resistance (Hall, 1995)
Resultant	Single vector that results from vector composition (Hall, 1995)
Sagittal plane	Plane in which forward and backward movements of the body and body segments occur (Hall, 1995)
Stretch-shortening cycle	Eccentric contraction followed immediately by concentric contraction (Hall, 1995)
Toe-off	The instant that the jumper loses contact with the ground
Velocity	Change in position with respect to time (Hall, 1995)
Weight	Attractive force that the earth exerts on a body (Hall, 1995)
Work	Expression of mechanical energy that is calculated as force multiplied by the displacement of the resistance in the direction of the force (Hall, 1995)

ABBREVIATIONS

BDJ	Bounce Drop Jump
CDJ	Countermovement Drop Jump
CM	Countermovement
CMJ	Countermovement Jump
COM	Centre of Mass
DDF	Drop Down Fast
DJ	Drop Jump
EFB	Explode From Bottom
EMG	Electromyography
GRF	Ground Reaction Force
MVC	Maximum Voluntary Contraction
PAR-Q	Physical Activity Readiness-Questionnaire
PO	Push-off
POT	Push Off Toes
SJ	Squat Jump
SSC	Stretch Shortening Cycle

1. INTRODUCTION

Vertical jumping ability is an important determinant of success in various competitive and recreational athletic activities. Coaches frequently use verbal cues (e.g., explode) to indirectly change the movement pattern or coordination strategy of an athlete's vertical jump, with the belief that performance can be enhanced (Orlick, 1986; Jones et al., 1988). However, there is a paucity of research to support this notion.

This study will focus on the countermovement jump (CMJ), which is a common movement in many sports (e.g., basketball, volleyball etc.). To execute a CMJ, the jumper starts from an erect position and then initiates a downward countermovement before initiating the push-off phase. During the push-off phase, the jumper exerts a force on the force platform that results in a ground reaction force (GRF). The force generates an impulse that accelerates the jumper's center of mass (COM) upwards. If sufficient impulse is produced, the jumper lifts off the ground and becomes airborne. The maximum jump height (i.e., displacement) of the jumper's COM is determined by the amount of impulse produced during the push-off phase prior to take-off.

It has been shown that the coordination strategy used when performing a vertical jump is robust and fairly constant even if the force producing capacity of the muscle changes (Bobbert & Ingen Schenau, 1988; Bobbert & van Soest, 1994; Bobbert & van Zandwijk, 1999; van Zandwijk et al., 2000). If the force producing characteristics of the muscle change, re-training of the nervous system is required for the body to optimize the coordination strategy (Bobbert & van Soest, 1994). A verbal cue may be used to optimize jump technique, it may also be used to speed up the learning/training process and allow an athlete to change their coordination strategies more quickly than by repetition/training alone. It is of great interest to coaches and researchers to determine if a cue can alter the coordination strategy of a jumper in such a way as to improve vertical jump performance (i.e., jump height).

One of the first published studies that documented vertical jumping ability was published by Sargent (1921) and was limited to a measure of jump height. With the advent of the force platform, a more detailed analysis of vertical jump dynamics is now possible (Bobbert et al., 1996; Bosco et al., 1981; Komi & Bosco, 1978). Using a force platform, the vertical component of the GRF can be sampled at high frequency. Force-time data from the force platform is then recorded on a computer. Variables such as acceleration, velocity, displacement and impulse, which cannot be accurately perceived by the naked eye, can be calculated with numerical integration of the force-time data. These variables can be graphed to create profiles or curves that represent the movement pattern or coordination strategy of an individual's vertical jump technique.

The primary objective of this study was to determine if cues can change CMJ technique, and secondarily to determine if cues can change CMJ height.

2. LITERATURE REVIEW

The purpose of this literature review is to examine the current scientific knowledge regarding cueing and vertical jump performance. There is a paucity of research that has been conducted examining the effects of cues on vertical jump performance. This review of literature will examine and describe various aspects of the vertical jump including: dynamics, classification of jumps and methods used to measure vertical jump performance. Literature examining coordination strategies and effects of instructions on vertical jump performance will also be reviewed.

2.1. Seminal vertical jump studies

This section will provide an overview of some of the earliest studies that have examined vertical jump performance.

Marey and Demeny (1885) conducted one of the very first studies that compared the squat jump (SJ) and CMJ to find that the CMJ was higher. Sargent (1921) presented the vertical jump test as a test of general physical performance and the "physical test of a man". The standing vertical jump test was thought to be a test of speed, strength, skill, energy, and involve the "...muscles of the feet, calves, thighs, buttocks, back, neck anterior deltoid, chest, and biceps". Davies (1968) used a force platform to study instantaneous power output produced during a vertical jump for both men and women. Davies followed up this initial work with a study in 1971 using a force platform to measure the instantaneous power output produced during a vertical jump and correlated this with body size and composition (Davies, 1971). Cavagna et al. (1971) compared SJ and CMJ using a force platform and concluded that there was not a significant difference in jump height. However, a post-hoc analysis was done on the data which found that take-off velocity was 6.4% ($P < 0.01$) greater for the CMJ (Asmussen & Bonde-Petersen, 1974).

Several researchers have used a force platform to determine how elastic energy is stored and then utilized during CMJ and drop jump (DJ) (Asmussen & Bonde-Petersen, 1974; Komi & Bosco, 1978). Asmussen (1974) studied the SJ, CMJ and DJ using a force platform to examine storage of elastic energy in muscles. A similar study was performed by Komi (1978) with a few differences in experimental design. A greater range of DJ heights were used and a comparison was made between men and women. It was found that the leg extensor muscles of the females were able to use a greater portion of the stored elastic energy in jumping activities, however men could sustain a higher stretch load. For all subjects jump height increased as drop height increased.

Results from a 60 second continuous jump test were used to calculate the average power output of leg extensor muscles (Bosco et al., 1983b). A subsequent study using the same test found that the average mechanical work calculated based on the test results were significantly correlated ($r = 0.69$, $p < 0.05$) with the percentage of fast twitch muscle fibers in the vastus lateralis (Bosco et al., 1983a). Use of the 60 second continuous jump test can be used to predict muscle fiber composition.

Bobbert et al. (1986), performed a biomechanical analysis of the DJ and CMJ using a force platform, video analysis, and electromyography (EMG). This study was the first of many studies published by Bobbert that examined the vertical jump (Bobbert et al., 1987; Bobbert & Ingen Schenau, 1988; Bobbert, 1990; Bobbert & van Soest, 1994; Bobbert et al., 1996; Bobbert & van Zandwijk, 1999).

In the past vertical jump performance has been used to study various parameters such as jump height, storage of elastic energy, power, and percentage of fast twitch muscle fibers. As technology developed, force platforms were commonly used in these studies. In summary, these studies show the growth of knowledge regarding vertical jump performance.

2.2. Types of Jumps

The method by which vertical jumps are performed can be classified into three different categories. These categories include the CMJ, squat jump (SJ) and drop jump (DJ)). A brief description of each is found below.

2.2.1. Countermovement Jump

The CMJ can be divided into two phases; the countermovement phase and the push-off phase. The jump starts with a downward countermovement from an upright standing position. The jumper drops down (flexing the knees and hips) causing an eccentric contraction in the major lower limb muscle groups including the knee and hip extensors. At the end of the countermovement, the jumper is in a crouched down or squatted down position. In this position the center of mass (COM) of the jumper's body is at its maximum downward displacement and the knees and hips are at their peak degree of flexion during the jump. The end of the countermovement and start of the push-off phase are marked with a transition from negative (downward) to positive (upward) velocity.

The push-off phase starts from a squatted down position. The jumper concentrically contracts the knee and hip extensors and plantar flexors of the ankles maximally during this phase to accelerate their COM upwards.

2.2.2. Squat Jump

Unlike the CMJ, a SJ begins from a static squatted down position. The SJ is exactly the same as a CMJ, only without the countermovement. By eliminating the countermovement, mechanisms such as the viscoelastic characteristics of the muscle and connective tissue and the stretch shortening cycle (SSC) do not make major contributions to impulse production and the resulting jump height.

2.2.3. Drop jumps

Drop jumps (a.k.a., depth jumps) are performed by dropping from a platform of a set height, often 20-100 cm. After stepping off a raised platform and falling down, the jumper decelerates the downward movement upon landing and without stopping, starts the push-off phase (Bobbert, 1990). Similar to the CMJ, the DJ utilizes the SSC. In a testing situation, the landing and subsequent jump are often performed on a force platform to record force-time data.

2.3. Dynamics of Vertical Jumping

Dynamics is a branch of mechanics dealing with systems subject to acceleration (Hall, 1995). If jump height is to be maximized, the primary objective of the jumper is to maximize velocity at lift-off. Equation 2.1 shows the relationship between maximum velocity and jump height. Lift-off can be defined as the instant immediately prior to toe-off where the value of the GRF falls below the bodyweight of the jumper. To maximize velocity at lift-off, impulse must be maximized. Equation 2.2 shows the calculation of velocity based on impulse. Impulse is defined as the product of force and the time over which the force acts (Hall, 1995). Equation 2.3 shows how impulse is calculated. To create as much impulse as possible, the jumper tries to exert a large magnitude of force for as long as he/she can.

Equation 2.1. Jump height is determined by velocity at lift-off which can also be referred to as maximum velocity.

$$h = (\tfrac{1}{2}\, v_{max}^2)/g \tag{2.1}$$

Where:

h = height of jump or displacement of center of mass [m]
v_{max} = maximum velocity [m/s]
g = acceleration due to gravity = 9.81 [m/s^2]

Equation 2.2. Maximum velocity is directly proportional to maximum impulse.

$$v_{max} = I_{max} / m \tag{2.2}$$

Where:

v_{max} = maximum velocity [m/s]
I_{max} = maximum impulse [N s]
m = mass of jumper [kg]

Equation 2.3. Impulse produced during vertical jumping.

$$I_2 = I_1 + (F_{measured} - F_{bodyweight}) * \Delta t \tag{2.3}$$

Where:

I = impulse [N s]
$F_{measured}$ = ground reaction force measured by the force platform [N]
$F_{bodyweight}$ = force due to the mass of the jumper [N]
Δt = change in time [s]

2.4. Coordination Strategies

A consistent pattern of neuromuscular activation and time histories of angular joint movement are used to perform a vertical jump (Bobbert & Ingen Schenau, 1988; Bobbert & van Soest, 1994; Bobbert & van Zandwijk, 1999; van Zandwijk et al., 2000). Even if the trunk segment was constrained, the pattern of activation remained the same between and within subjects when jumping (Eloranta, 1996). Luhtanen (1978) found that there were similarities in the contributions of individual segments to take-off velocity among individuals. Bobbert (2001) describes a similarity between experimental results and simulation results.

It has been proposed that a learning process or training program is required to optimize the coordination pattern when there is a change in force producing characteristics of muscle (i.e. loss or gain in strength) (Bobbert & van Soest, 1994). For example, if there is an increase in strength of the knee extensors, the coordination strategy must adapt to accommodate those strength gains and increase jump height.

In summary, a robust coordination pattern is used to perform a vertical jump. Repetitive training may be employed to alter the coordination strategy to optimize jump performance.

2.5. Review of methods used to measure jump height

This section will review a number of methods used to measure vertical jump performance. Vertical jump tests vary in ease of administration, practicality, accuracy, and number of parameters measured.

2.5.1. Jump and Reach

The jump and reach test is one of the simplest and most commonly used vertical jump tests. When performing a jump and reach test the jumper attempts to touch the highest point on the wall. The test can be performed with or without a countermovement and with or without an arm swing (CSEP Expert Advisory Committee, 1998; Smilios, 1998). The jump and reach test requires very little equipment (i.e. a wall, measuring tape and chalk) and can be performed almost anywhere. The Vertec apparatus (M-F Athletic Company, Cranston, RI) can be used instead of a wall and chalk. The Vertec has been used to measure vertical jump height in a number of studies (Ashley & Weiss, 1994; Thomas et al., 1996; Harman et al., 1991; Newton et al., 1999). The Vertec apparatus is comprised of a free standing pole that has a series of horizontal plastic bars or fingers attached to the top portion of the pole. These fingers are easily knocked out of position by a jumper's swinging arm. The jumper attempts to move the highest horizontal bars that can be reached, out of place at the peak of the jump. For both the Vertec and the wall touch, jump height is measured as the difference between the highest point reached by the tips of the fingers of one arm while standing upright with one arm reaching as high as possible and the highest point on the wall or Vertec apparatus that is touched while the jumper is in the air. Only jump height is measured by the test. The accuracy of the measured jump height is questionable since the jump height measured is highly dependent on the jumper's ability to touch the wall or apparatus at the exact moment he/she is at peak jump height. Some advantages of the test are that it is relatively inexpensive, gives instantaneous feedback of jump height results, it is easy to administer and can be performed almost anywhere.

2.5.2. Switch Mat Tests

Switch mats are used to measure flight time and then calculate jump height. When using a switch mat, jump height is calculated based on the time between when the jumper loses contact with the mat and when the jumper lands.

Equation 2.4. Calculation of jump height based on flight time.

$$h = \tfrac{1}{2}g(\Delta t/2)^2 \qquad (2.4)$$

Where:

h = jump height [m]
g = acceleration due to gravity = 9.81 [m/s^2]
Δt = flight time [s]

In order to obtain flight time data that accurately predicts jump height, the subject must land in exactly the same body position as when he/she loses contact with the mat. Very often flight times are exaggerated because at take-off the knees are fully extended while during the initial stage of landing the knees are slightly bent to absorb the impact of landing. This results in the jumper's COM at landing to be 1-4 cm lower than at takeoff. This leads to a 0.5-2 cm over estimate of the true flight height (Linthorne, 2001; Kibele, 1998).

2.5.3. Belt Tests

The University of Toronto Belt Jump is described by Klavora (2000). The test involves a device consisting of a measuring tape with a belt at one end, rubber mat, and a tape feeder attached to the mat. When the jumper jumps, the measuring tape that is attached to the belt around the jumper's waist is pulled through the tape feeder directly below the jumper. Jump height is measured by the length of tape that is pulled through the tape feeder. The tape feeder is designed to provide minimum resistance to the tape as it is being pulled through so that jump height is not decreased due to the downward pull of the tape. This test is portable, and relatively inexpensive. Unlike the jump and reach test, the belt test is not dependent on the jumpers ability to touch the wall at peak jump height. Since the belt jump test directly measures the displacement of the jumper's waist the test can be performed with or without an arm swing. The belt jump test can also be performed with and without a countermovement. Similar to the jump and reach test, only jump height or displacement of the jumper's waist is measured.

2.5.4. Cinematography

Kinematics is defined as the study of the description of motion, including considerations of space and time (or a description of the appearance of motion). Cinematography can be used to measure the kinematics of a jump. The vertical jump can be recorded on film in a sagittal view for a two-dimensional analysis of the vertical jump. A segmental model of the body is then constructed with joints such as the ankle, knee, hip and shoulders defining the end of the segments. The weight and location of the COM of the segments can be estimated based on Dempster's center of gravity model (Dempster, 1955). The film is then analyzed frame by frame. The film speed is known and constant therefore the time between frames is known. Movement (i.e., displacement) of the body segments that occur between frames is then measured to determine angular displacement of the joints. From this data, time-derivative data such as velocity and acceleration can be computed. By combining the kinematic data and the segment masses, angular torque and power about joints can be calculated. Ground reaction forces can only be calculated (not measured) based on the kinematic data. However, the contribution of individual segment movement to GRF can be determined.

Some major disadvantages of this form of measurement are that it is expensive, analysis can be very time consuming, analysis has to be done by a qualified person very knowledgeable in biomechanics and it generally does not provide instantaneous results. Advantages of film analysis are the ability to measure contributions of individual body segments to the GRF.

Today, the most advanced kinematic analysis systems use infrared cameras with infrared reflectors placed on the subject's joint centers. The movement of the reflectors is recorded, digitized and then analyzed using a computer. Examples of companies which sell such products for cinematographic analysis include Peak Performance Technologies (www.peakperform.com), Ariel Dynamics (www.sportscience.org) and BioVison Sports (www.biovisionsports.com).

2.5.5. Force Platform

Force platforms have a wide range of applications, including real-time weight measurement (i.e. truck scales), automobile crash tests, clinical gait analysis and sports technique analysis. A force plate is composed of piezoelectric transducers at each corner which produce voltage when they are compressed. The voltage produced is proportional to the force applied. The force is calculated based on the magnitude of the electrical output signal. The data is passed from the force platform to a computer which records the force-time data at frequencies up to 2000 Hz (Toumi et al., 2001). After the raw force-time data is obtained further calculations can be done. Acceleration, velocity, displacement, power, impulse and work are all values which can be calculated based on the force-time data acquired from the force plate.

When a subject performs a vertical jump, that subject exerts a force on whatever surface that person is jumping on. According to Newton's third law, if that surface is rigid, an equal and opposite force is applied to the subject. This force is often referred to as the GRF. If jumps are performed on a force platform, the GRF can be measured directly.

The vertical force exerted on the force platform is dependent on the mass of the jumper and the vertical movement of the COM. It is important to note that all the force values measured by the force platform are representative of the motion of the COM of the jumper. If the jumper is standing still, the force platform will register the force due to the COM or bodyweight. If the jumper is starting to drop down (i.e., countermovement) the force measured will be less than bodyweight since the jumper's COM is accelerating downwards. When the jumper pushes against the platform during the push-off phase the force measured by the force platform will be greater than bodyweight since the COM of the jumper is accelerating upwards. Video analysis must be performed to determine which body segments moved to produce the GRF at any given time. However, the various phases of the vertical jump (i.e., countermovement, push-off, flight time) can be roughly distinguished by looking only at the force-time data. The advantages of using a force platform include: direct measure of ground reaction forces, fast calculation of results, portability and extremely high frequency of data collection (i.e., 2,000 Hz).

While data from the force platform is only representative of the COM movement, it is capable of providing very useful information about the coordination strategy or technique used by the jumper. The data from the force platform can also be analyzed much faster than by conventional video analysis methods.

2.6. Effects of Cues and Instructions on Athletic Performance

The effects of cues, instructions and thought content on the kinetics and kinematics of movements during specific sport skills has not been thoroughly investigated. Cues are often used by coaches to alter the movements of athletes with the intention of improving the athlete's execution of a given sport skill (Orlick, 1986; Jones et al., 1988). Optimal performance of sport skills leads to improved performance in sport.

In the past, the majority of research studies have focused on the performance outcome or final results after a cue or particular instructions have been used. Rushall (1975, 1979) was one of the first to emphasize the potential value of using specific types of thoughts to enhance performance of athletic activities. Verbal cues were used to help students focus attention on key elements of handstands and forward roll (Masser, 1993). The cue "shoulders over your knuckles" led to improved handstand performance in children. The cues "forehead on knees" and "keep yourself in a tight ball" resulted in significant improvement in forward roll performance. Rushall and Shewchuck (1989) found that swim times improved when swimmers were told to think of the cues "blast", "rip", "push", "elbows up", and "lean on the shoulder". Thoughts that concentrated on the cues "Go! Blast, punch, looong" "drive, drive" "rip, rip" "up-hill quick and grip" significantly improved cross-country skiing times (Rushall, 1988). A significant increase in bowling scores of male league bowlers was observed with the use of instructions such as "reach out for the pins, or shake hands with the pins" (Hill & Borden, 1995). Research has shown that the use of cues or particular thought content can lead to improvements in performance. However, this literature has failed to study the changes in the specific dynamic variables that result in performance improvement.

A few studies have investigated dynamic variables for non-sport specific movements. Cues used by trained rowers showed increases in the kinetic variable of force during a hand dynamometer test (Rushall, 1982; Rushall, 1984). Acceleration, reaction time and velocity were measured during the action of pointing at a target with different instructions (Fisk & Goodale, 1989). Fisk (1989) found that the time to initiate hand and eye movement decreased when subjects were told to point to a target "as quickly as you can". When subjects were told to point "as accurately as you can" and "quickly and accurately" the acceleration time of the hand did not change, but the period of deceleration was increased. These studies investigated how different instructions affected the kinetic and kinematic variables. Unfortunately, the movements or skills studied were not specific to an athletic activity (i.e., jumping).

Overall, very little research has been done that investigates the use of cues and thought content and their effect on movement and athletic performance. The studies discussed here have shown improvements in performance with the use of cues. However, these studies failed to describe the changes in dynamic variables that led to the improvements in performance. There is a scarcity of research that has examined the use of cues and the associated changes in biomechanical variables which lead to improved athletic performance.

2.7. Effects of Cues and Instructions on Vertical Jump Performance

Coaches frequently use verbal cues (i.e., explode) to indirectly change the movement pattern or coordination strategy of an athlete's vertical jump, with the belief that performance can be enhanced (Orlick, 1986; Jones et al., 1988). Very little research exists which examines the effects of instructions on jump performance. Articles that have examined the effects of instructions on vertical jump performance are summarized below.

The effect of instructions on jump height and contact time related to CMJ and DJ performance have been studied before (Young et al., 1995). The instructions were as follows: CMJ – jump for maximum height (no instructions relating to amplitude or speed of countermovement), DJ-H – jump for maximum height, DJ-H/t- for maximum height and short contact time, DJ-t - for minimum contact time. Values for jump height and contact time were measured. Jump height for the CMJ was higher than all DJ. Only values of jump height, contact time, and height/contact time were reported. The order of jump conditions from best to worst were: CMJ, DJ-H, DJ-H/t, DJ-t. Contact times became shorter as jumping instructions changed from DJ-H to DJ-H/T to DJ-T. From this data we know that contact time and jump height varied depending on the instructions given.

Bobbert (1986) reported that strikingly different DJ techniques were used by handball players when the only instructions were to keep hands on hips and jump for maximum height. Based on the results the subjects were categorized into two groups: approximately half the subjects were categorized into a group where the push-off phase was <200 ms and the other group where the push-off phase was >260 ms. A subsequent study investigated the effect of instructions on jumping technique and the biomechanics of the jumps (Bobbert et al., 1987). Three different types of jumps were performed which included the CMJ, countermovement drop jump (CDJ), bounce drop jump (BDJ). The instructions for the CDJ were "do this more gradually by making a larger downward movement upon landing, comparable to the one made during CMJ" while the BDJ required the jumpers to "reverse the downward velocity into the upward one as soon as possible after landing". Mean ground contact time was less for BDJ. The force and power production was larger for the BDJ, but jump height was less than CDJ. CMJ had the greatest depth at 37 cm, CDJ 25 cm and BDJ 13 cm. The duration of the movement occurred in this order BDJ < CDJ < CMJ in order of depth. Jump height BDJ < CDJ = CMJ, with BDJ being only slightly less than CDJ. The results showed that the jump techniques varied in ground contact time, jump height, depth of countermovement and power.

Collectively, these studies report variables such as jump height, contact time, push-off time and depth of countermovement. However, other variables such as countermovement time and impulse production distribution that help to describe how the jump profiles (i.e. acceleration, velocity, displacement) varied between the jumps has not been reported. In addition, the effects of cues such as drop down fast (DDF), explode from bottom (EFB) and push-off toes (POT) have not been previously examined.

3. STUDY RELEVANCE

The CMJ is frequently used in many sports including soccer, gymnastics, diving, figure skating, football, basketball and volleyball. If it can be shown that jumping technique can be altered with verbal cues it would be of great interest to researchers and coaches. A cue may be used to optimize jump technique, it may also be used to speed up the learning/training process and allow an athlete to change their coordination strategies more quickly than by repetition/training alone.

By understanding vertical jump data it allows coaches and trainers to help an athlete fine tune their jump technique so they are able to improve their performance. Changes in performance can be quantified and monitored over time by measuring such variables as total time, countermovement time, push-off time, depth of countermovement, jump height and distribution of impulse production. Jump height and flight time are no longer the only variables that can be used to describe vertical jump performance.

This study is directed to furthering our understanding of the effect of cues on vertical jump performance by examining numerous variables which include acceleration, velocity, jump height, depth of countermovement, countermovement time, push-off time, contact time, and distribution of impulse production during the CMJ.

4. OBJECTIVES

The objectives of this study were twofold:

1) To determine if cues can change vertical CMJ technique.

2) To determine if cues can change vertical CMJ height.

5. HYPOTHESES

Hypothesis 1:

H_0: $\mu_1 = \mu_2$; non-cued and cued CMJ have equivalent techniques

H_1: $\mu_1 \neq \mu_2$; non-cued and cued CMJ do not have equivalent techniques

Hypothesis 2:

H_0: $\mu_1 = \mu_2$; non-cued and cued CMJ have equivalent jump height

H_1: $\mu_1 \neq \mu_2$; non-cued and cued CMJ do not have equivalent jump height

6. LIMITATIONS & DELIMITATIONS

The limitations of this study were:

1) Only the movement of the COM based on GRF was measured. Video analysis was not used to correlate movement of body segments with GRF.
2) EMG was not used to measure the magnitude of muscle activation or the pattern of muscle activation.
3) Only males subjects aged 18 to 35 were tested.
4) A combination of trained and untrained males were studied.

The delimitations of this study were:

1) Subjects with non-cued jump heights less than 30 cm will be excluded from the study.

7. ASSUMPTIONS

The assumptions of this study were:

1) Maximal effort is given by the subject to jump as high as they can for all the jumps.

2) Subjects are receptive to the cues and instructions. Scripted instructions are reviewed with each subject and the cues are posted on the wall in front of the subject. The subject is reminded to pay attention to those cues and instructions at all times.

3) There will be adequate recovery time between the single jumps so as not to fatigue the subjects in such a way that jump performance would be affected. Due to the short duration and anaerobic nature of the vertical jump it is likely that 45 seconds rest between single jumps provides an adequate amount of recovery time.

8. METHODOLOGY

8.1. Experimental design

This study is a within-subject design examining the effects of cues on vertical jump technique and performance. Fifteen variables were examined based on force-time data measured by a force platform.

8.2. Subjects

Thirty-six apparently healthy male volunteers were recruited to participate in this study.

8.2.1. Inclusion Criteria

1) To participate in this study subjects had to be apparently healthy non-smoking males between the ages of 18 to 35 years.
2) Subjects agreed to refrain from any form of exercise other than their regular daily living activities on the day of the test and for one day prior to the day of testing.
3) Subjects were required to complete a Physical Activity Readiness-Questionnaire (PAR-Q) stating that they were presently free of muscle or joint injury and know of no medical reason which would indicate that participating in this research would be of any risk (APPENDIX A).

8.2.2. Exclusion Criteria

1) Subjects outside the above specified inclusion criteria were excluded.
2) Subjects that were not able to obtain an average vertical jump height of 30 cm during the non-cued jumps were also excluded.

8.2.3. Recruitment

Volunteer subjects were recruited through public postings. Subjects were required to read and sign an informed consent form and a PAR-Q prior to participation in the study. Subjects were not responsible for any costs directly related to this study, nor were they provided any reimbursement for their participation in the study.

8.2.4. Ethical approval

All subjects were required to give their written consent after being informed of the nature of the experiment. The protocol was accepted by the Education/Nursing Research Ethics Board of the University of Manitoba (APPENDIX B).

8.3 Procedure

8.3.1. Testing protocol

The experimental procedure was performed in the following order. Select components of the experimental procedure are described later in the Methodology.

Upon arrival at the Human Performance Laboratory (HPL) the following procedures occurred:

i. each subject was required to review and endorse a copy of the Informed Consent and PAR-Q.

ii. the height and weight of each subject was measured and recorded.

iii. each subject performed 5-minutes of stationary cycling at 75 W to serve as a warm-up for the jumping tasks.

iv. scripted instructions (Figure 8.1), cues and jumping stages (Figure 8.2) were reviewed with each subject.

v. each subject was required to complete 2 consecutive Jumping Stages (Figure 8.2) in the following order: a) non-cued jump stage, b) cued jump stage.

vi. a single maximal non-cued jump was performed after the cued jump stage was completed.

vii. in total, each subject was required to perform 13 maximal effort jumps.

8.3.2. Countermovement Jump (CMJ)

All jumps performed in this study were maximal CMJ performed with hands on hips at all times. The CMJ started from an upright standing position. From this position the jumper performed a rapid countermovement which involves dropping down into a squatted position. The countermovement was immediately followed by a push-off phase where the jumper rapidly extends the hips and knees and plantar flexes the ankles to accelerate upwards.

8.3.3. Warm-up and orientation

After a 5-minute warm-up on a Monark stationary cycle at 75 W, scripted instructions (Figure 8.1), cues and jumping stages (Figure 8.2) were reviewed with each subject.

SCRIPTED INSTRUCTIONS

The following instructions will be given prior to each jump:

- I will give the same instructions ("**HANDS ON HIPS**" and "**START**") before each jump.
- When I say "**HANDS ON HIPS**" assume a *READY* position (hands on hips, stand upright, feet shoulder width apart and look ahead).
- When I say "**START**" you begin the downward movement.
- After landing, stand upright and remain still.
- ALL JUMPS ARE TO BE PERFORMED WITH HANDS ON HIPS AND LOOKING STRAIGHT AHEAD.
- *Rehearse READY position.*

Do you understand?

Follow these instructions AT ALL TIMES:

ALWAYS JUMP FOR:

A: <u>MAXIMUM HEIGHT</u>

B: <u>WITH HANDS ON HIPS</u>

C: <u>WITH CONTINUOUS MOTION</u>

These instructions will be posted on the wall at all times (indicate wall).

Do you understand?

Figure 8.1. Scripted instructions for subject.

8.3.4. Jump Stages

The study protocol was divided into two stages which included: 1) Non-cued jumps 2) Cued jumps. A summary of the testing protocol is diagramed in Figure 8.2.

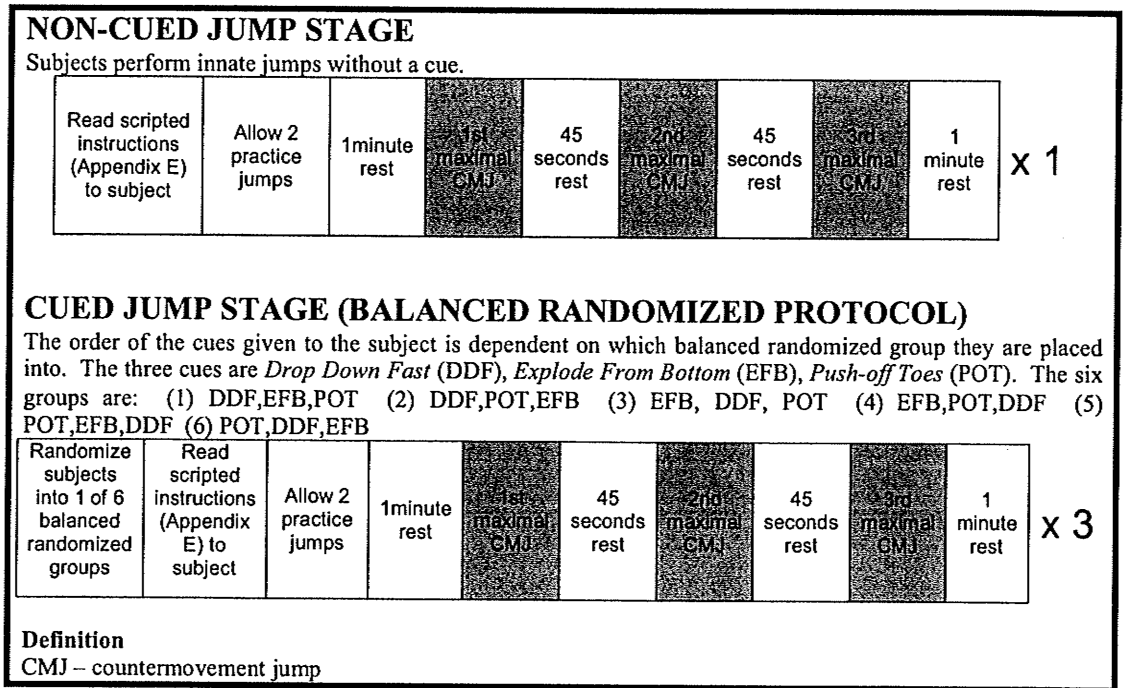


Figure 8.2. Testing protocol timeline.

8.3.4.1. NON-CUED JUMP STAGE

After the scripted instructions had been reviewed with the subject, two practice jumps were performed followed by 1 minute of rest. Three individual jumps with 45 seconds rest in between jumps were performed. In this stage all jumps were performed without a cue to record the jumper's innate technique.

8.3.4.2. CUED JUMP STAGE

The scripted instructions were reviewed with the subject again. Two practice jumps and three individual jumps were performed and measured using *each cue*. There was one minute of rest after the practice jumps and 45 seconds rest between the individual jumps. The order of the cues given to the subject was dependent on which balanced randomized group they were placed into. The three cues were *Drop Down Fast* (DDF), *Explode From Bottom* (EFB), *Push-off Toes* (POT). The six groups were: (1) DDF, EFB, POT (2) DDF, POT, EFB (3) EFB, DDF, POT (4) EFB, POT, DDF (5) POT, EFB, DDF (6) POT, DDF, EFB. The appropriate cue was posted on the wall in front of the jumper at all times.

8.3.4.3. NON-CUED SINGLE JUMP

After the cued jump stage was completed, scripted instructions were reviewed with the subject (Figure 8.3). The subject was allowed a minimum of one minute to rest before performing the final jump.

INSTRUCTIONS PRIOR TO LAST JUMP:

I would like you to use your natural jump technique similar to the non-cued stage and disregard the previous cues used.

Do not think of a cue. Just concentrate on these instructions (point to instructions posted on the wall and read).

ALWAYS JUMP FOR:

A: MAXIMUM HEIGHT

B: WITH HANDS ON HIPS

C: WITH CONTINUOUS MOTION

There is no cue.
"HANDS ON HIPS" → "START"

Figure 8.3. Scripted instructions given before final jump

8.4. Research Instruments

The following research instruments were used:

1. Electronic Scale (Tanita Digital Scale BWB 800S) to measure bodyweight.
2. Height measured using a stadiometer.
3. Kistler instrumented force platform (Kistler Quattro Jump 9290, Kistler Instrument Corporation, Amherst, NY), with a surface area of 0.9m x 0.9m.
4. Computer based data acquisition system operating with Windows 95 and Quattro Jump data acquisition software (Kistler Instrument Corporation, Amherst, NY)

8.5. Force-time Measurement Protocol

8.5.1. Force Platform and Data Acquisition Equipment

The vertical component of the ground reaction force of all jumps was sampled and recorded at 500 Hz using a force platform (Kistler Quattro Jump 9290, Kistler Instrument Corporation, Amherst, NY), a personal computer running Microsoft Windows 95 and the data acquisition software Quattro Jump (Version 1.03, Kistler Instrument Corporation, Amherst, NY). The force platform was connected to a personal computer via a serial cable. The force plate has dimensions of 920mm x 920mm x 125mm.

8.5.2. Force Platform Calibration

The force platform was calibrated before each stage of jumping using the "Pulse Reset/Operate" function in the Quattro Jump program.

8.6. Calculations of Profiles

This section will review how the profiles of acceleration, velocity and displacement were calculated based on force-time data measured by the force platform. Figures showing the profiles of these parameters are used to identify the various stages of the jump. All equations used are summarized in APPENDIX C.

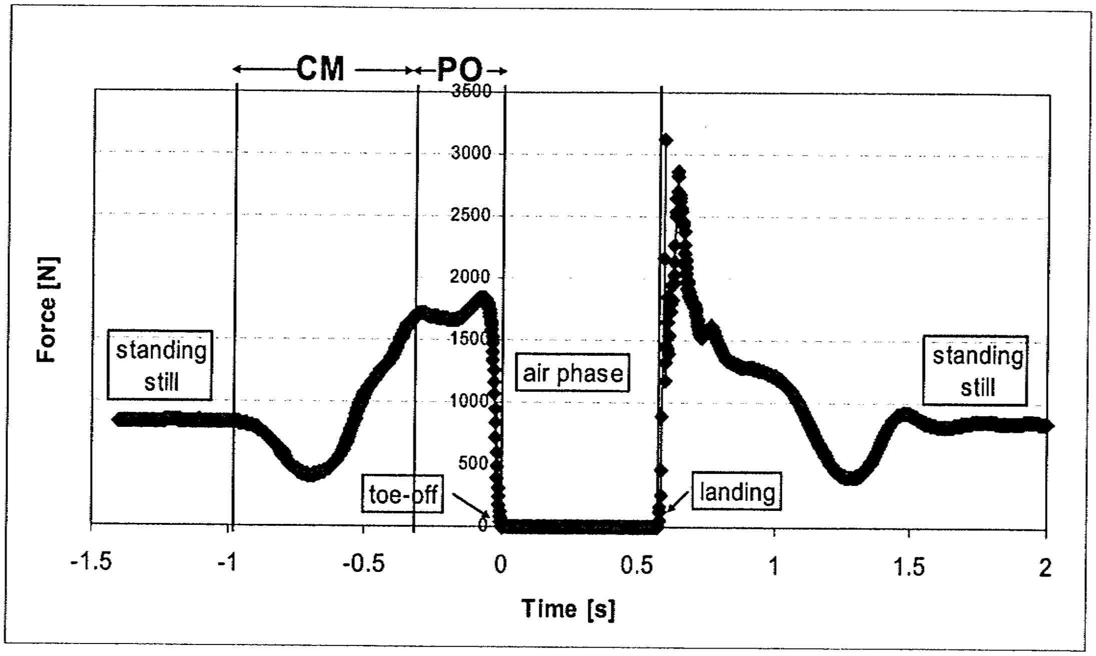


Figure 8.4. Force-time data output from force platform.

Figure 8.4 contains the raw force-time data profile that was recorded by the force plate during a single jump. The weight of the subject can be obtained from the raw data profile by looking at the plateau values at the very beginning and end of the data when the subject is standing upright and still. Looking at only the raw data profile, the general motions of the jumper can be identified, including the countermovement, push-off, toe-off, air phase and landing. We can only approximate where the transition from the countermovement to the push-off occurs looking at the force-time data. Landing can also be identified, but for the purpose of this study the data after toe-off will be discarded. All pertinent data that determines jump height is recorded prior to toe-off.

After all the data shown in Figure 8.4 was collected, the force-time data was exported to a spreadsheet program for analysis and further calculations. After being exported, the data was trimmed prior to the start of the countermovement and after toe-off. This extraneous data is not required in the calculations of the jump profiles (i.e. acceleration, velocity, displacement). Figure 4 shows the net acceleration and velocity versus time after the raw force-time data has been trimmed. The net acceleration profile is directly proportional to the force profile since F=ma and the jumper's mass is constant.

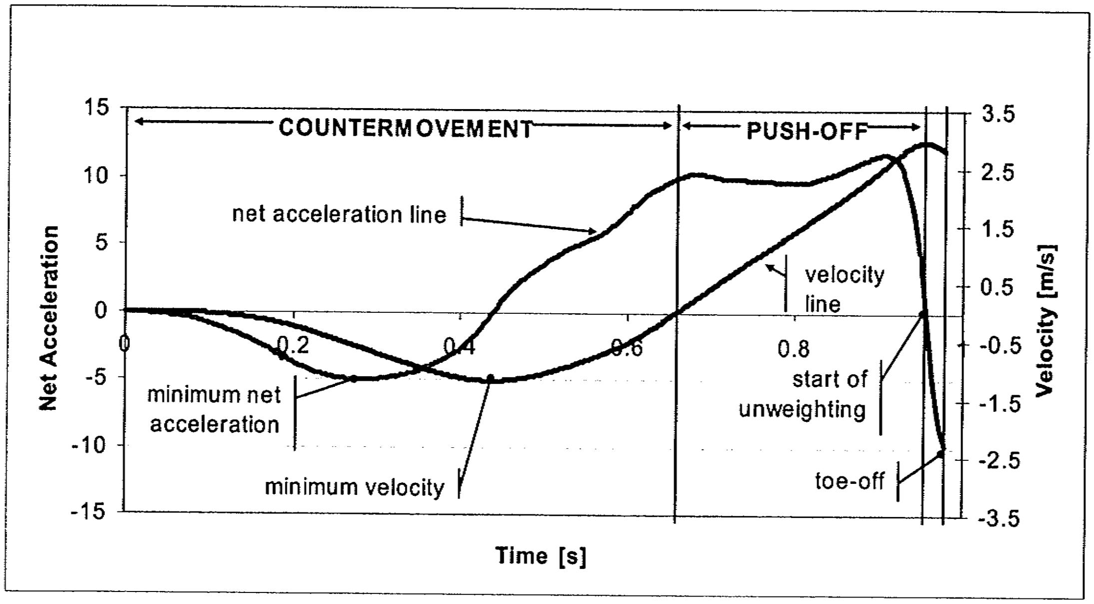


Figure 8.5. Net acceleration and velocity versus time.

Equation 8.1. Net acceleration of the jumper's COM.

$$a_{net} = (F_{measured} - F_{bodyweight}) / m \tag{8.1}$$

Where:

a_{net} = net acceleration [$m \cdot s^{-2}$]
$F_{measured}$ = ground reaction force measured by the force platform [N]
$F_{bodyweight}$ = force due to the mass of the jumper and the acceleration of gravity [N]
m = mass of jumper [kg]

Equation 8.2. Velocity of the jumper's COM.

$$v_2 = v_1 + a_{net}\Delta t \tag{8.2}$$

Where:

v_1 = velocity at point 1 [m·s]
v_2 = velocity at point 2 [m·s]
a_{net} = net acceleration [$m \cdot s^{-2}$]
Δt = change in time [s]

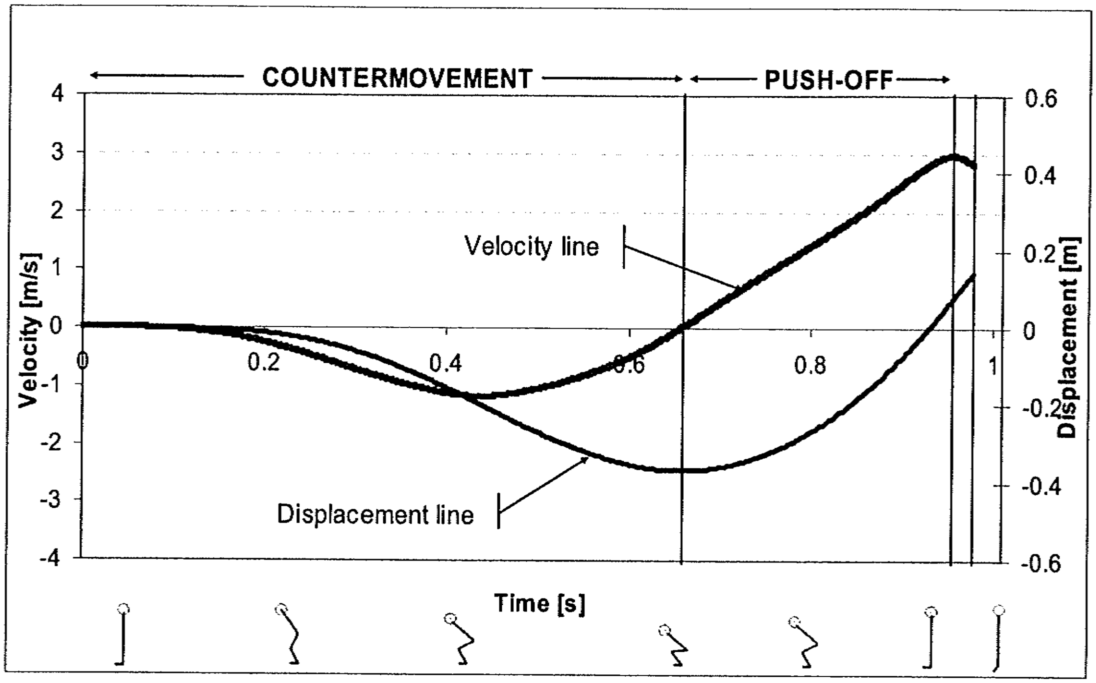


Figure 8.6. Velocity and displacement versus time.

Figure 8.6 shows velocity and displacement versus time. Equation 8.3 was used to calculate displacement. Downward displacement of the jumper's COM occurs during the countermovement until maximum negative (downward) displacement is reached at the end of the countermovement. The end of the countermovement is marked by maximum negative displacement and velocity changes from negative to positive.

Equation 8.3. Displacement of the jumper's COM.

$$d_2 = d_1 + v_1 \cdot \Delta t + \tfrac{1}{2} a_{net} \Delta t^2 \tag{8.3}$$

Where:

d = displacement [m]
v = velocity [$m \cdot s^{-1}$]
Δt = change in time [s]

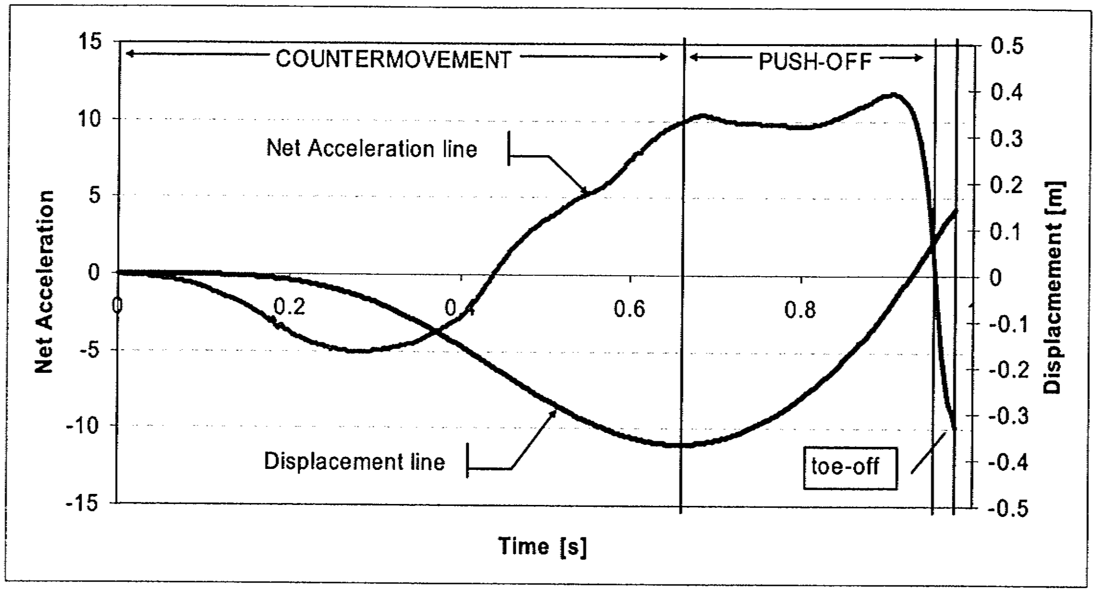


Figure 8.7. Net acceleration and displacement versus time.

Figure 8.7 is similar to Figure 8.6 except displacement is shown instead of velocity. Net acceleration and displacement have been discussed previously.

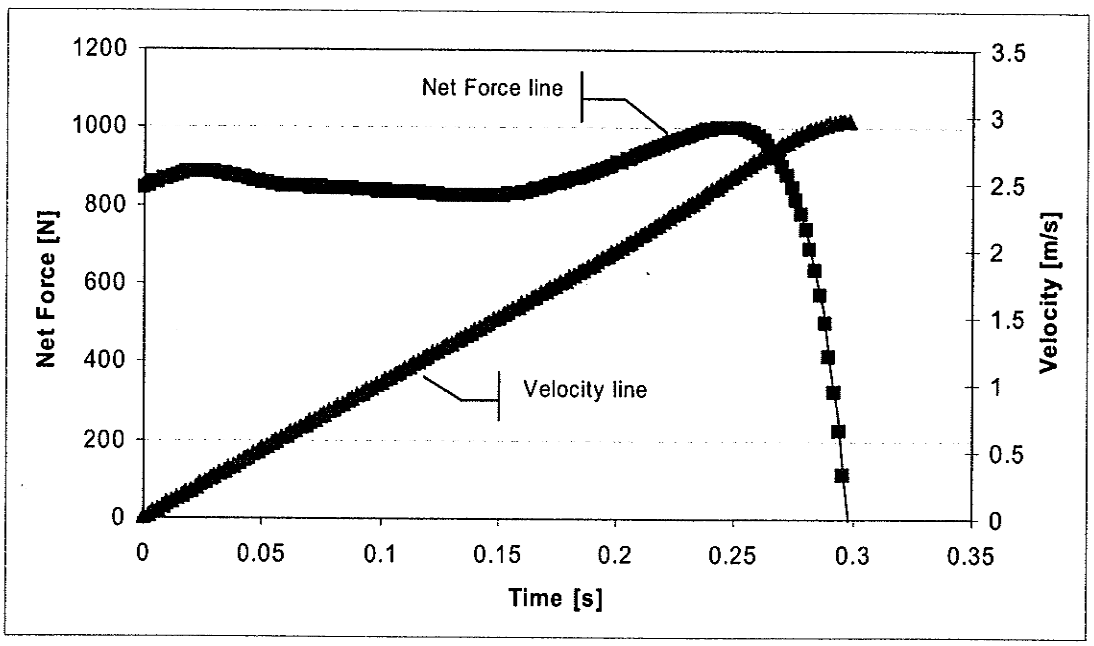


Figure 8.8. Net force and velocity during the push-off phase.

Figure 8.8 depicts the net force and velocity during the push-off phase. Equation 8.4 was used to calculate net force. The graph has excluded the values between "start unweighting" and "toe-off" (reference Figure 8.5). There is not any force or impulse production in that time and therefore the data in that phase does not affect jump height.

Equation 8.4. Calculation of net force.

$$F_{net} = F_{measured} - F_{bw} \tag{8.4}$$

Where:

F_{net} = net force [N]
$F_{measured}$ = ground reaction for measured by the force platform [N]
F_{bw} = force due to the mass of the jumper [N]

Take-off velocity and jump height are determined by the amount of impulse produced. Equation 8.5 shows the calculation of impulse. Equation 8.6 shows that impulse is directly proportional to velocity which results in identical impulse and velocity profiles shapes. Equation 8.7 shows the calculation of jump height based on take-off velocity.

Equation 8.5. Calculation of impulse.

$$I_2 = I_1 + (F_{measured} - F_{bw}) \cdot \Delta t \tag{8.5}$$

Where:

I = impulse [N s]
$F_{measured}$ = ground reaction for measured by the force platform [N]
F_{bw} = force due to the mass of the jumper [N]
m = mass of jumper [kg]
Δt = change in time [s]

Equation 8.6. Maximum velocity is dependent on maximum impulse produced and mass.

$$V_{apex} = I_{apex} / m \tag{8.6}$$

Where:

v_{apex} = maximum velocity [m/s]
I_{apex} = maximum impulse [N s]
m = mass of jumper [kg]

Equation 8.7. Calculation of jump height based on take-off velocity.

$$h = (\tfrac{1}{2}\, v_{apex}^{2})/g \tag{8.7}$$

Where:

h = height of jump or displacement of center of mass [m]
v_{apex} = maximum velocity [m/s]
g = acceleration due to gravity = 9.81 [$m{\cdot}s^{-2}$]

Impulse can be increased by increasing the duration force production is maintained and/or by increasing the magnitude of force produced. Looking at Figure 8.8, the area under the net force-time profile represents the total or maximum impulse produced.

It is important to note that velocity is a relative measure (to mass) and impulse is an absolute measure. For example two jumpers of different body mass may produce exactly the same magnitude of impulse. However, the lighter jumper will jump higher since the same impulse acted on a lower mass.

The values of total impulse, apex velocity and jump height are all directly related. Of these three values, this study was focused on jump height since it is the variable that is commonly associated with jump performance and most people are familiar with.

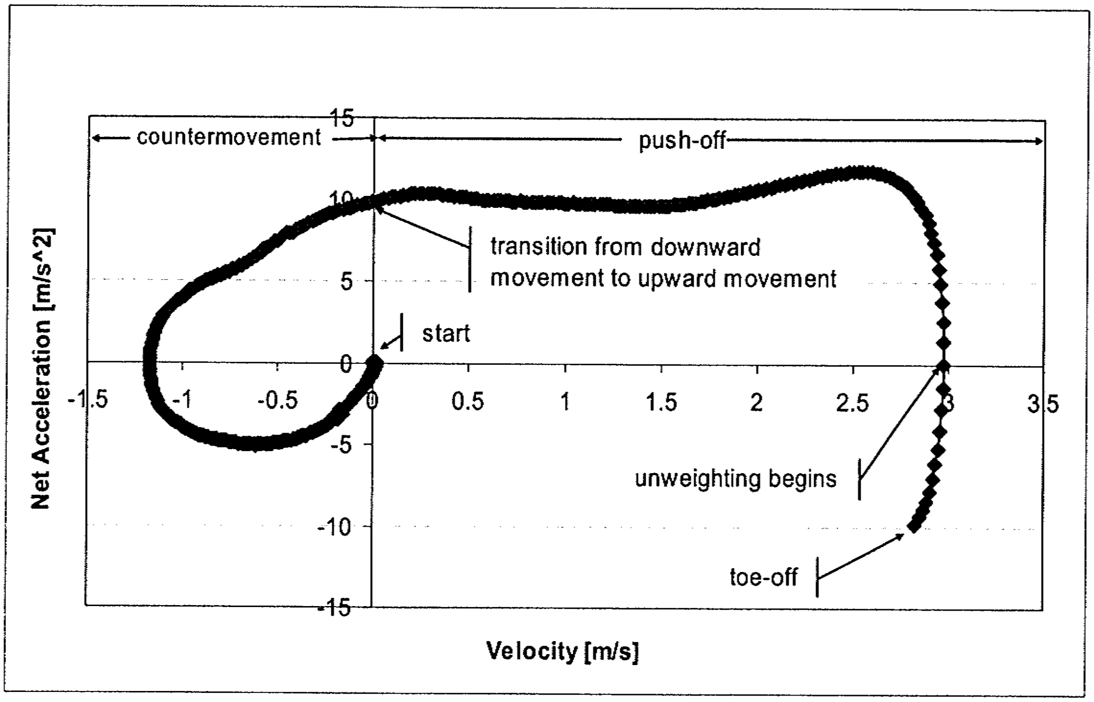


Figure 8.9. Net acceleration versus velocity.

Figure 8.9 shows the acceleration and velocity of the COM in both the countermovement and push-off phases of the jump. Values such as minimum and maximum acceleration and velocity and acceleration at zero velocity are all resultants of the jumper's neural activation patterns and movement. The overall profile shown in Figure 8.9 is a resultant of the jumper's technique. Analogous to a fingerprint, the profile can be unique to an individual's jump technique.

8.7. Calculation of Dependent Variables

The force-time data was exported into Microsoft Excel where the acceleration, velocity, displacement and impulse profiles were calculated. There are 16 variables which were selected from the profiles and then analyzed. Figures 8.10, 8.11, and 8.12 illustrate the variables used to describe the acceleration, velocity, displacement and impulse profiles. Figures 8.13 and 8.14 summarize the graphs and all 15 variables. These variables were exported into SPSS for further analysis.

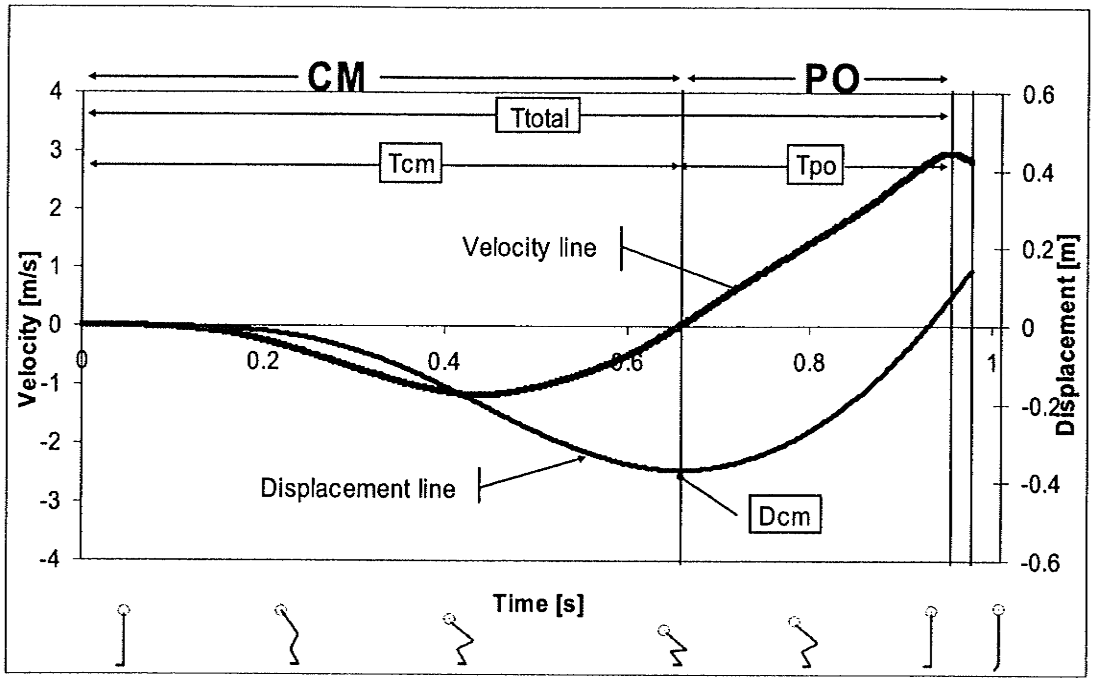


Figure 8.10. Variables shown on velocity and displacement profiles.

Table 8.1. Variables from velocity and displacement profiles.

	Variable	Description
1	Dcm	Maximum downward (negative) displacement of the center of mass at the end of the countermovement (CM)
2	Tcm	Countermovement time
3	Tpo	Push-off time
4	Ttotal	Total time

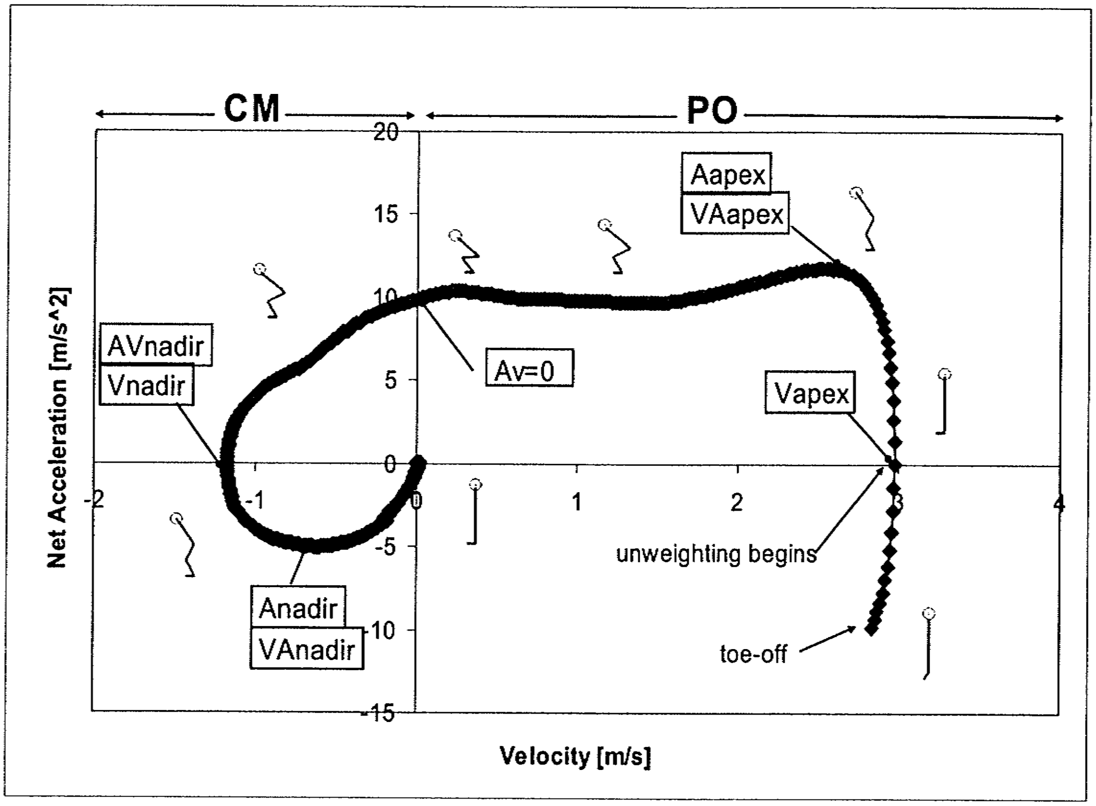


Figure 8.11. Variables on net acceleration versus velocity profile.

Table 8.2. Variables from net acceleration versus velocity profile.

	Variable	Description
5	Vnadir	Minimum velocity
6	AVnadir	Net acceleration at minimum velocity
7	Anadir	Minimum net acceleration
8	Vanadir	Velocity at minimum acceleration
9	Av=0	Net acceleration at zero velocity at the bottom of the countermovement
10	Aapex	Maximum acceleration
11	Vaapex	Velocity at maximum acceleration
12	Vapex	Maximum velocity

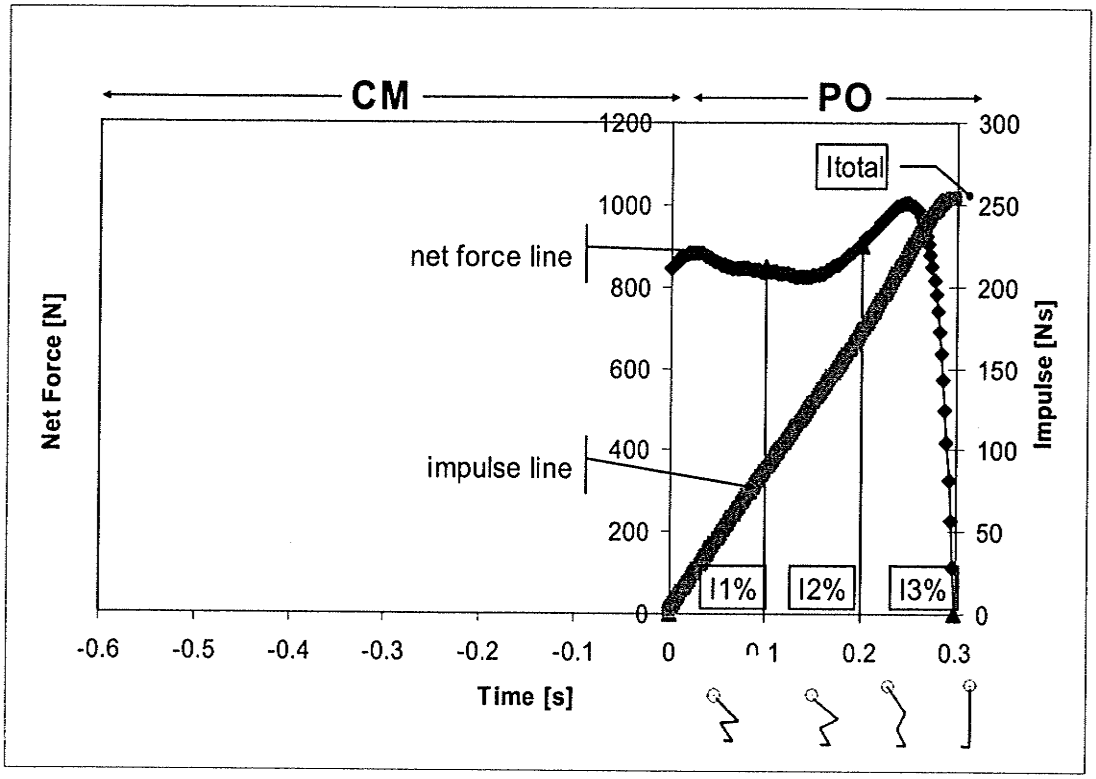
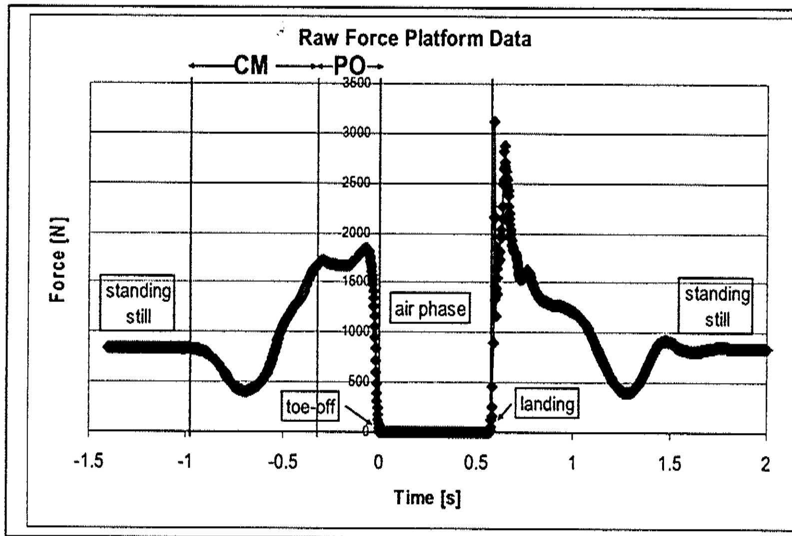
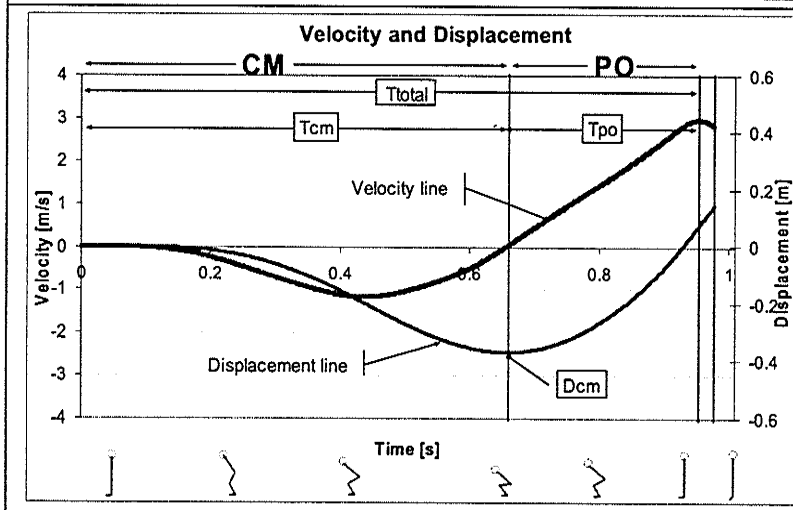


Figure 8.12. Variables on net force and impulse profiles.

Table 8.3. Variables from net force and impulse profiles.

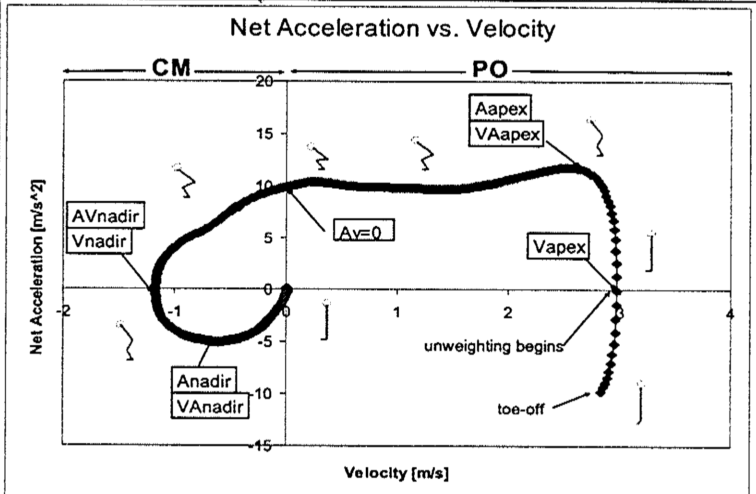
	Variable	Description	
	Itotal	Total impulse = total area under net force vs. time graph	
	Impulse1, Impulse2, Impulse3	Magnitude of impulse produced in the respective thirds of the push-off [Ns]	Area underneath the net force line
13,14,15	I1%, I2%, I3%	Fraction of total impulse produced during the respective thirds of the push-off	i.e. I1% = Impulse1 / Itotal * 100
16	JH	Jump height	Vapex = Itotal / m JH = (½ $Vapex^2$)/g

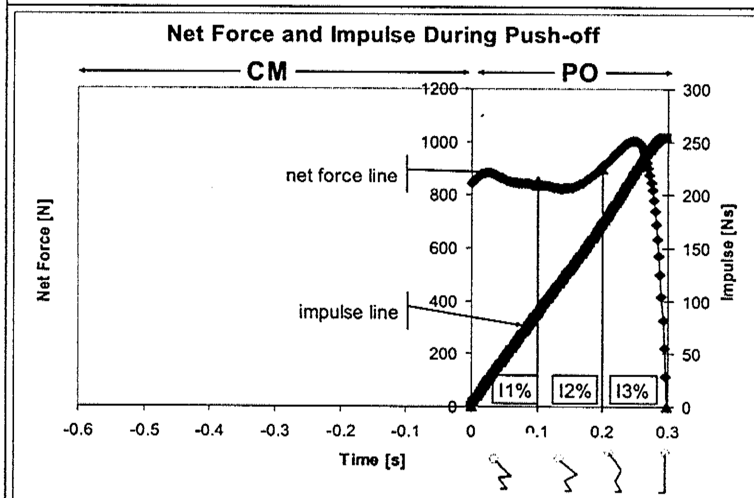




		Profiles that are calculated based on the Force-time profile:	
		Anet	Acceleration is the rate of change of velocity
		V	The speed and direction of movement of the COM
		D	Displacement of the COM
		I	Impulse = force * time during the PO. Impulse determines jump height
1	**CM**	Dcm	How far the COM drops from the standing position at the start of push-off
2	**CM**	Tcm	Time between initiation of CM and start of PO
3	**PO**	Tpo	Time between start of PO and when the jumper starts to lift off the platform
4	**CM & PO**	Ttotal	Total time – time between initiation of CM and when the jumper starts to lift off the platform

Figure 8.13. Summary of variables. ***CM** – countermovement, **PO** – push-off, **COM** – center of mass of the jumper





5	CM	Vnadir	Greatest downward velocity
6		AVnadir	Acceleration when Vnadir occurs
7		Anadir	Greatest downward acceleration & point when the jumper "puts on the brakes" to slow the rate of descent
8		VAnadir	Velocity when Anadir occurs
9	PO	Av=0	Acceleration at the transition from countermovement to push-off
10		Aapex	Greatest positive acceleration
11		VAapex	Velocity when Aapex occurs
12		Vapex	Greatest upward velocity
13	PO	I1%	Percentage of total impulse produced during the first third of the push-off
14		I2%	Percentage of total impulse produced during the second third of the push-off
15		I3%	Percentage of total impulse produced during the last third of the push-off
16		JH	Jump Height (JH) $v_{max} = I_{total} / m$ $JH = (\frac{1}{2} v_{max}^2)/g$

Figure 8.14. Summary of variables. ***CM** – countermovement, **PO** – push-off, **COM** – center of mass of the jumper.

8.9. Statistical Methods

A repeated measures analysis of variance (ANOVA) was used to analyze the main effect of cue/condition, main effect of trial number and interaction effect of condition x trial on the 15 variables associated with vertical jump performance. The repeated measures ANOVA was performed using a 4 X 3 (condition x trial) model. Conditions 1, 2, 3, and 4 represented the non-cued, DDF, EFB, and POT conditions respectively. Three trials (i.e., single jumps) were performed for each condition. Significant differences for the main effect of condition (i.e., cue) and trial number were followed up with a Tukey's *post hoc* pairwise comparison. The *post hoc* analysis for the main effect of condition compared the non-cued condition to each cued condition. Differences between cued conditions were not investigated.

Based on the repeated measures ANOVA, a significant main effect of cue/condition shows an effect of one or more of the cues on the variable being tested. A significant main effect of trial number indicates that if we ignore the cue, the given variable being analyzed varied depending on the trial number. If the interaction effect (cue x trial number) is significant it tells us that the effect of the trial number was stronger for at least one of the cues. (Refer to Tables 9.2, 9.3, and 9.4 for F Statistics of the results.)

9. RESULTS

9.1. Subjects

Thirty-six male volunteer subjects (Table 9.1) participated in the study.

Table 9.1: Subject characterisitics.

Characteristic	Mean ± SD	Range
Age (years)	24.2 ± 4.5	18 - 34
Mass (kg)	77.5 ± 12.0	53.5 - 103.4
Height (cm)	180.8 ± 9.8	161.2 - 202.5
Body Mass Index ($kg \cdot m^{-2}$)	23.7 ± 3.0	17.0 – 29.0

9.2. Vertical Jump Dynamics

9.2.1. Main & Interaction Effects of Cue x Trial RM ANOVA

A significant main effect of cue (Table 9.2 and 9.3) was demonstrated by all dynamic jump variables, except 'time of push-off phase' (Tpo). The push-off time may be highly dependent on the force-length-velocity characteristics of the primary force producing muscles. The force producing characteristics of the muscles are dependent on many variables including genetics (e.g., percentage of fast twitch fibres) and state of training.

A significant main effect of trial was demonstrated by Dcm (displacement of COM during the countermovement phase; Table 9.2) and I3% (percentage of impulse produced during the last third of the push-off phase; Table 9.3), but not by any other dynamic jump variables. Possible explanations for main effect of trial on Dcm and I3%

are addressed in the discussion section. No significant interaction effects of cue x trial occurred for the dynamic jump variables.

Table 9.2. F Statistics (RM ANOVA) for all Countermovement Dynamic Variables.

	Counter Movement Phase Dynamic Variables					
	Dcm	Tcm	Vnadir	AVnadir	Anadir	VAnadir
Effect Cue	**8.6#**	**8.5#**	**23.4#**	**6.5****	**27.1#**	**4.3***
Trail	**4.6***	0.5	2.6	1.9	1.0	0.1
Cue x Trial	1.4	1.3	0.9	1.7	2.4	0.7

(*P<0.05; **P<0.01 #p<0.001).

Table 9.3. F Statistics (RM ANOVA) for all Push-Off Phase Dynamic Variables.

	Push-Off Phase Dynamic Variables							
	Tpo	Av=0	Aapex	VAapex	I1%	I2%	I3%	Ttotal
Effect Cue	2.4	**16.0#**	**11.3#**	**6.5****	**13.8#**	**5.4****	**8.8#**	**8.7#**
Trail	0.3	1.1	1.0	0.2	2.9	3.1	**3.8***	0.4
Cue x Trial	1.1	0.9	0.9	0.6	0.4	0.7	0.6	1.7

(*P<0.05; **P<0.01 #p<0.001).

9.2.2. Tukey Post Hoc Analysis of Cue

Figures 9.1, 9.2, and 9.3 illustrate the results of the post hoc analysis of the variables associated with the countermovement phase, push-off phase and total time (Ttotal) respectively.

9.2.2.1. *Drop-Down Fast vs. Non-Cued.* The cue "drop-down fast" (DDF) had a significant effect, compared to the non-cued condition, on all of the dynamic variables except for Dcm (displacement of COM during countermovement phase) and Tpo (Time or duration of push-off phase).

9.2.2.2. Explode From Bottom vs. Non-Cued. The cue "explode from bottom" (EFB) had a significant effect, compared to the non-cued condition, on the following dynamic variables: Dcm, Vnadir, Anadir, I1% and I2%.

9.2.2.3. Push-Off Toes vs. Non-Cued. The cue "push-off toes" (POT) did not have a significant ($P<0.05$) effect, compared to the non-cued condition, on any of the dynamic variables during either the countermovement or push-off phase of the vertical jump (see Appendix D for summary of mean data).

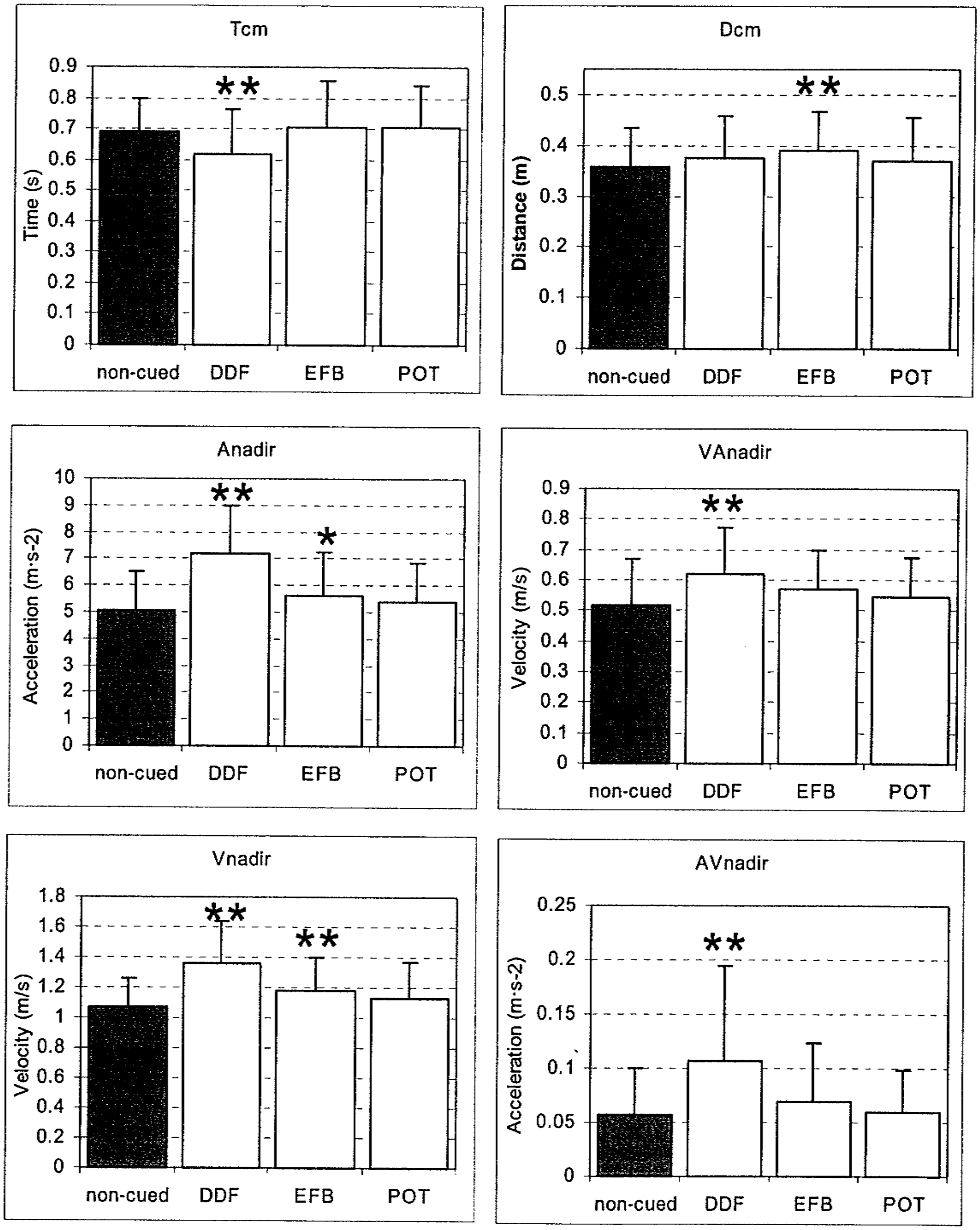


Figure 9.1. Variables associated with the countermovement. Each *bar* represents the mean ± SD of all subjects (*P<0.05, **P<0.01).

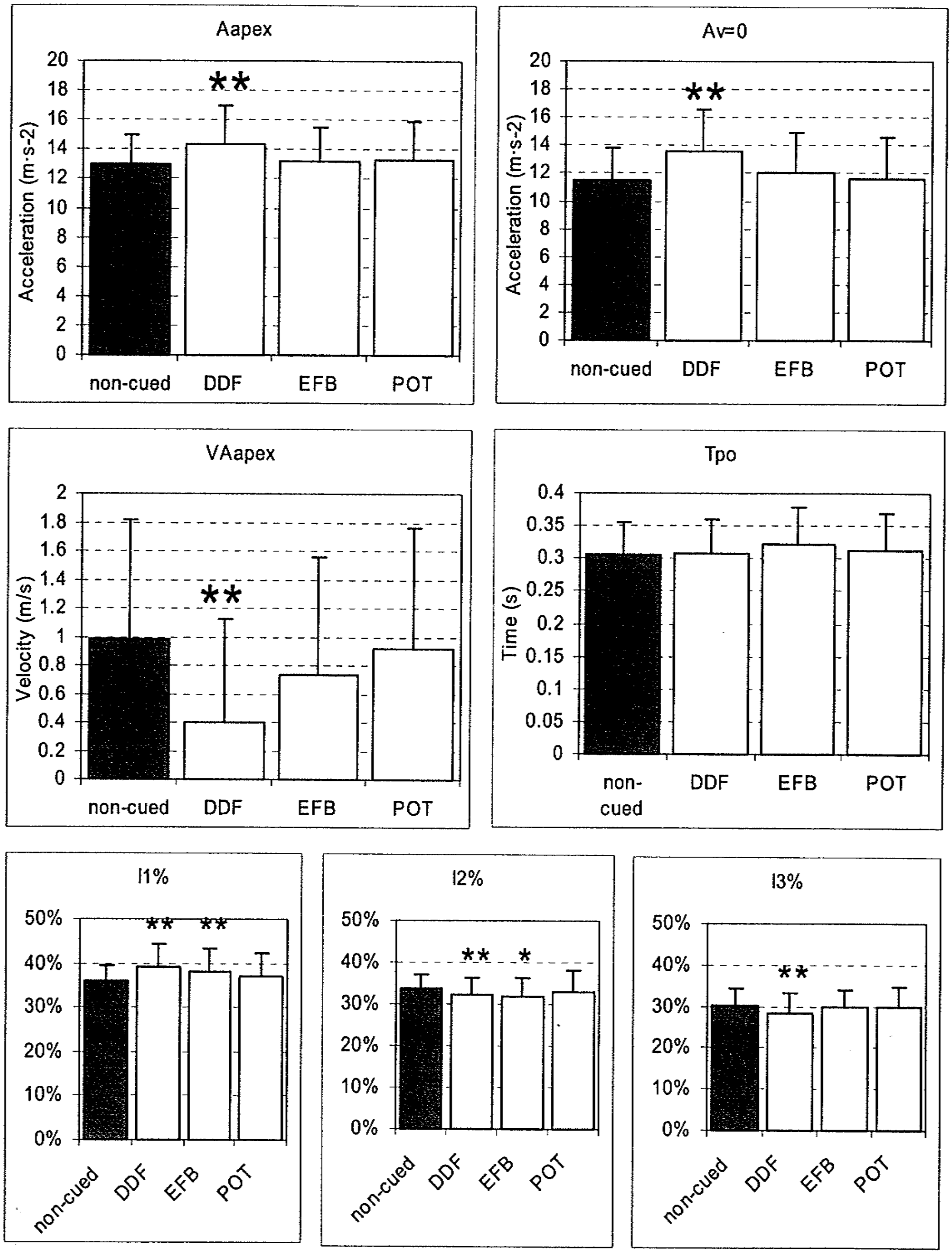


Figure 9.2. Variables associated with the push-off phase. Each *bar* represents the mean ± SD of all subjects (*P<0.05, **P<0.01).

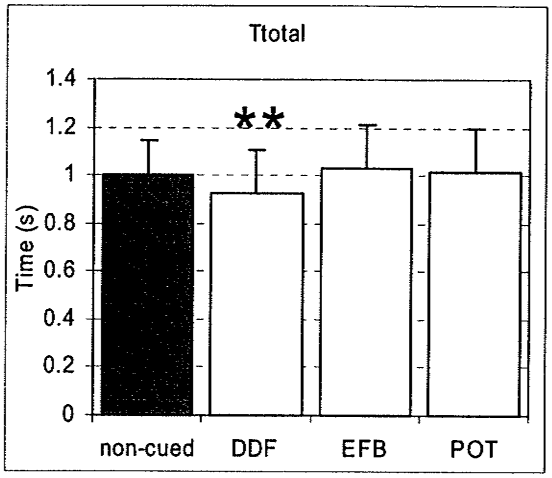


Figure 9.3. Total time to perform countermovement and push-off (Ttotal). Each *bar* represents the mean ± SD of all subjects (*P<0.05, **P<0.01).

9.2.3. Tukey Post Hoc Analysis of Trial

Trial number had a significant effect (P<0.05) on the downward displacement of the COM during the countermovement (Dcm). During trial#2 the COM dropped an average of 0.66 ± 1.3 cm lower (P<0.01) than during trial#1. During trial#3 the COM dropped an average of 0.65 ± 1.7 cm lower (P<0.05) than during trial#1.

Trial number also had a significant effect on the I3% (percentage of impulse produced during the last third of the push-off phase). During trial#2 the percentage of total impulse produced during the last third of the push-off (I3%) was 0.37 ± 0.80 % greater (P<0.01) than during trial#3.

9.3. Vertical Jump Height

9.3.1. Main & Interaction Effects of Cue x Trial RM ANOVA

A significant main effect of cue (Table 9.4) and cue x trial interaction effect were demonstrated by jump height.

Table 9.4. F Statistics (RM ANOVA) for Jump Height.

		Jump Height
Effect	Cue	**4.0#**
	Trial	1.0
	Cue x Trial	**3.5****

(*P<0.05; **P<0.01 #p<0.001).

9.3.2. Tukey Post Hoc Analysis of Cue

There where no significant (P<0.05) differences in jump height when the cued condition was compared to the non-cued conditions (Figure 9.4). The significant main effect of cue appeared when the following comparisons were made: DDF vs. EFB and EFB vs. POT (Tukey's post hoc analysis; P<0.05 and P<0.01 respectively).

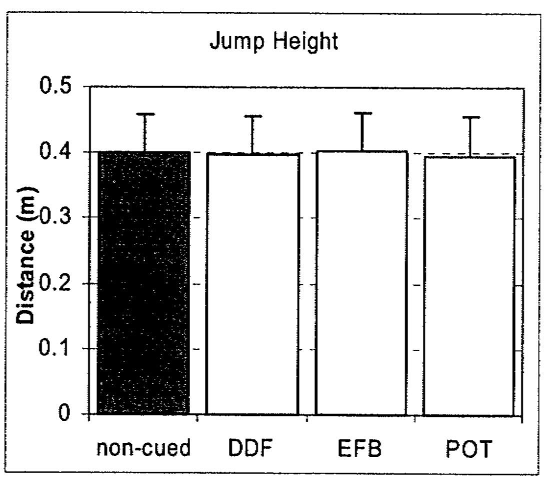


Figure 9.4. Mean ± SD jump height for all conditions.

9.3.3. Tukey Post Hoc Analysis of Cue x Trial Interaction Effect

One hundred and fifty three pair-wise comparisons would have to be performed to determine where the interaction effect occurred. Post hoc analysis already revealed that there was not a significant main effect of cue when all the cued conditions were compared to the non-cued condition. Further post hoc analysis to determine where the interaction effect occurred would not provide much useful information to address the objectives of this study.

9.4. Analysis of Jump Height for Non-cued Jumps Before and After the Cued Jump Stage

Data for a single non-cued jump was collected for 30 subjects at the end of the test session after all the cued jumps were completed. For the 30 subjects tested, the mean jump height of the first three non-cued jumps did not differ significantly ($p<0.05$) from the non-cued jump performed after all the cued jumps (39.7 ± 6.0 cm vs. 39.7 ± 6.3 cm, respectively).

9.5. Summary of Results

The cue "drop-down fast" (DDF) had a significant effect, compared to the non-cued condition on 12 of the 14 variables associated with jump technique. The cue "explode from bottom" (EFB) had a significant effect, compared to the non-cued condition, on 5 of the 14 variables associated with jump technique. The cue "push-off toes" (POT) did not have a significant effect, compared to the non-cued condition, on any of the variables. Jump height (JH) was not significantly effected by any of the cues, compared to the non-cued condition.

A main effect of trial was observed for the variables Dcm (displacement of COM during the countermovement phase) and I3% (percentage of impulse produced during the last third of the push-off phase). Post hoc analysis of the main effect of trial number revealed small but statistically significant differences between trials for both variables.

10. DISCUSSION

The primary objective of this study was to determine if cues can affect changes in vertical jump dynamics. The results of this study indicate that some of the dynamic variables for the DDF and EFB conditions were significantly different from the non-cued condition. The secondary objective was to examine the effect of cues on vertical CMJ height. Despite changes in the dynamic variables, the results showed that jump height did not change when the non-cued condition was compared to the cued conditions.

Prior to data collection it was surmised that each cue (DDF, EFB, and POT) would have distinct effects on specific phases of the jump. Only the cue DDF partially matched our expectations as the subjects performed a faster countermovement and reduced total jump time (i.e. response time). When the cue DDF was used the acceleration at the start of the push-off (Av=0) did increase, but high force production was not maintained throughout the push-off and total impulse production did not increase. It was suspected that the cue EFB would result in the push-off starting with a more explosive movement, however this was not the case. If the jumper had been more 'explosive' at the beginning of the push-off phase greater impulse would have been produced. Near maximal muscular contractions may have already been occurring at the beginning of the push-off making it impossible to produce significantly higher forces. It was also expected that the cue POT would result in greater GRF and therefore greater impulse production during the time immediately prior to lift-off, but this effect was not observed. It is possible that subjects were already pushing off their toes maximally during the non-cued jumps.

Although coaches frequently use cues to help an athlete improve a skill, previous studies have not examined the effect of cues on vertical jump performance (Jones et al., 1988; Orlick, 1986). Young (1995) investigated the effects of lengthy, detailed instructions on drop jump performance and found that the instructions affected jump height, contact time, and height/contact time. Our study analyzed many other variables besides jump height and contact time to describe CMJ performance. There are no studies to date that have investigated vertical jump performance using any of the same cues or combination of dynamic variables analyzed in this study.

10.1. Drop Down Fast (DDF)

10.1.1. Countermovement Phase

As expected, the jumpers performed the countermovement faster when the cue DDF was used compared with the non-cued condition. An increase in magnitude of the following variables was observed during the countermovement; Anadir, VAnadir, AVnadir and Vnadir.

The 'time of countermovement phase' (Tcm) decreased significantly ($P<0.01$) while the 'time of push-off phase' (Tpo) remained the same. As a result, it took less time to perform the complete jump (Ttotal). When the cue DDF is used the jumper is able to reach the same peak height in less time when compared to the non-cued condition. This effect of cue improves athletic performance. For example, a volleyball player is able to reach peak height to block in less time when the cue DDF is used.

10.1.2. Push-off Phase

The increase in Av=0 (acceleration when velocity is momentarily zero at the transition from countermovement to push-off) coincides with a greater GRF at the transition point from countermovement to push-off. This gives the force-time profile a higher starting point on the force axis (Figure 10.1) and contributes to greater impulse production at the start of the push-off phase. This shift in the force-time profile is demonstrated by the increase of I1% and the decrease of I2%. The shift in impulse production is also concurrent with the increase in Aapex (greatest positive acceleration) and the occurrence of Aapex closer to the transition from countermovement to push-off (i.e., VAapex decreased).

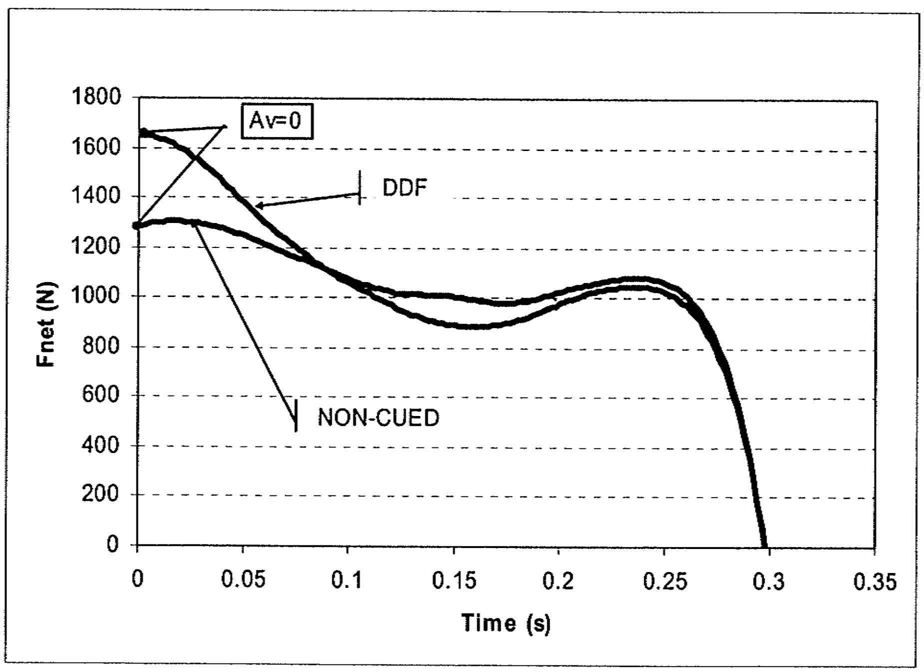


Figure 10.1. Representative force-time profiles during the countermovement for non-cued and DDF conditions of a single subject.

10.1.3. Summary

It becomes apparent by looking at the acceleration-velocity profile (Figure 10.2) that many of the dynamic variables are highly dependent on the preceding variables on the acceleration profile starting with the downward acceleration (Anadir). As the downward acceleration increased in magnitude, the downward velocity (Vnadir) and acceleration at the transition from countermovement to push-off (Av=0) increased in magnitude. This occurred because the jumper's COM was falling faster than during the non-cued condition and traveled the same distance (Dcm). Therefore, more braking force (i.e., deceleration) was required to stop the descent. As Av=0 increased, there was a shift in impulse production that occurred. Aapex increased resulting in a greater percentage of impulse being produced during the first third of the push-off (I1%) and less impulse produced during the second and last third of the push-off (I2%, I3%). Although the cue DDF did not lead to greater jump height, it did decrease the total time of the jump. An improvement in performance was made by decreasing total jump time.

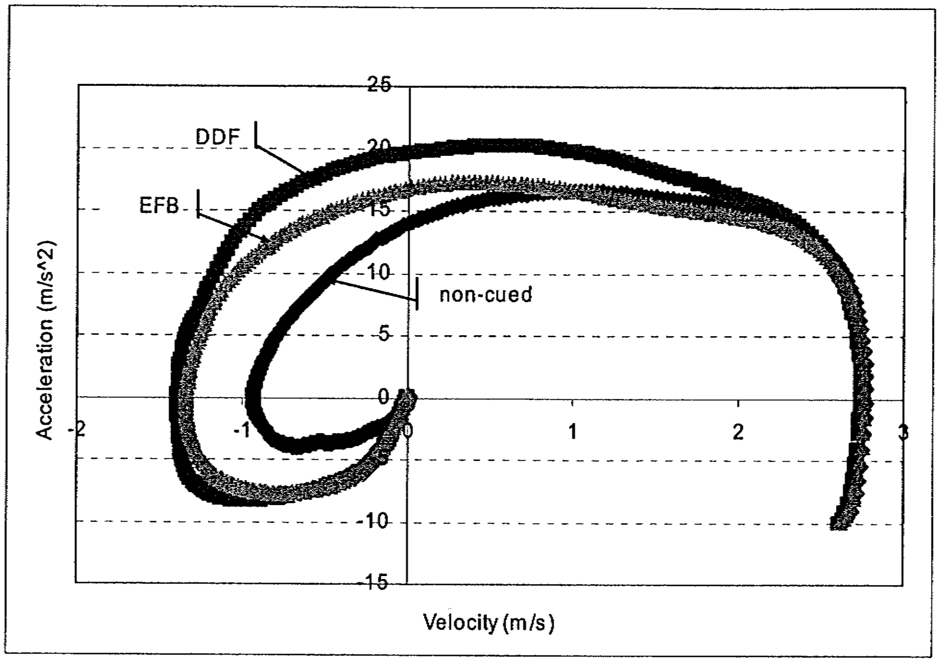


Figure 10.2. Representative acceleration-velocity profile of the non-cued, DDF, and EFB conditions for one subject.

10.2. Explode From Bottom (EFB)

10.2.1. Countermovement Phase

The cue EFB did not affect as many dynamic variables as the cue DDF. The following dynamic variables were effected; Dcm, Vnadir, Anadir, I1% and I2%. The magnitude of the change of these variables was less than the DDF condition. However, the pattern of the changes (i.e., increase or decrease) was the same for all five variables. For example I1% increased for the cues DDF and EFB while I2% decreased for both cues. Vnadir ($P<0.01$) and Anadir ($P<0.05$) were significantly greater in magnitude when compared to the non-cued condition. Figure 10.2 illustrates that the acceleration-velocity profile for EFB falls in between the non-cued and DDF profile.

The cue EFB resulted in a deeper countermovement when compared to the non-cued condition. This may be because the subject was more cognizant of "the bottom" and squatted down lower so that there was a greater distance to explode or accelerate upwards.

Since the depth of countermovement (Dcm) increased and the time between initiation of the countermovement and the start of push-off (Tcm) did not differ significantly from the non-cued condition it follows that Vnadir and Anadir were greater in magnitude. In other words Tcm was the same but a greater distance was traveled for EFB so the countermovement must have been faster.

10.2.2. Push-off Phase

Similar to the cue DDF, the percentage of impulse produced during the first third of the push-off (I1%) increased while the percentage of impulse produced during the second third of the push (I2%) decreased. The impulse distribution is dependent on the force-time profile during the push-off. A combination of statistically insignificant changes in Tpo, Aapex, VAapex, and Av=0 may explain the statistically significant differences in I1% ($P<0.01$) and I2% ($P<0.05$) for the EFB condition.

10.2.3. Summary

Figure 10.2 shows that the acceleration-velocity profile of the EFB condition falls in between the DDF and non-cued conditions. The cue EFB had a similar effect on the acceleration-velocity profile that DDF had. However, the overall effect that the cue EFB had on the acceleration profile was less than the cue DDF. This is reflected by the fact that the cue EFB affected 5 of the dynamic variables compared to the 12 dynamic variables affected by the cue DDF.

10.3. Push-off Toes (POT)

The cue POT did not result in a significant difference in any of the variables measured when compared to the non-cued condition. A possible explanation is that the subjects were already maximally pushing off their toes when performing the non-cued jumps. It may be possible that the cue POT would alter a jumper's technique if the jumper was not pushing off their toes (plantar flexing the ankle) maximally during the non-cued jumps.

10.4. Jump Height

Jump height (JH) and the time between the start of the push-off and when the jumper starts to lift off the platform (Tpo) did not change significantly with any of the cues. Although the cues DDF and EFB affected vertical jump dynamics, jump height remained unchanged for all cued conditions when compared to the non-cued condition. Based on this study, it appears that vertical jump technique is independent of jump height within subjects. It also appears as though each individual has a maximum or finite amount of impulse to produce in the same amount of time during the push-off (Tpo).

Bobbert (1994) suggested that if the strength of the muscles used in jumping increase, athletes would have to adapt their jump technique to make use of the increase in muscle strength and increase jump height. Logically it follows that by optimizing jump technique, jump height could be increased or the opposite, if jump technique worsens, jump height would decrease. We observed significant changes in jump technique but no changes in jump height for any of the conditions. This is contrary to Bobbert's conclusion that changes in jump technique would lead to changes in jump height. Conclusions from Bobbert (1994) were based on simulation data and data from subjects that performed SJ with no countermovement. Unlike Bobbert's study, a countermovement was included in our testing protocol. Our study demonstrated that changes in the countermovement resulted in significant changes in impulse distribution during the push-off. It appears that the countermovement allows for significant changes in technique while the jumper is still producing the same amount of total impulse (e.g., jump height) during the push-off when jumpers are told to jump maximally.

10.5. Main Effect of Trial

Trial number had a significant effect on the variables Dcm (depth of countermovement) and I3% (percentage of impulse produced during the last third of the push-off). The depth of countermovement (Dcm) was greater than trial#1 for trial#2 ($P<0.01$) and trial#3 ($P<0.05$) (37.0 ± 7.6 cm vs. 37.6 ± 7.6 cm, 37.6 ± 7.7 cm, respectively). A possible explanation for the deeper countermovement is that the subject became more accustomed to the movement pattern and therefore felt at ease dropping lower during trial#2 and trial#3.

During trial#2 the impulse produced during the last third of the push-off (I3%) was greater ($P<0.05$) than trial#3 (29.7 ± 4.4% vs. 29.3 ± 4.2%, respectively). It could be that the subjects were less motivated to maximally push-off during the entire push-off and subconsciously adjusted their technique to produce less impulse during the last stages of the push-off (i.e., I2% and I3%).

It was thought that the inclusion of two practice jumps prior to the three trials would be adequate to allow the jumper to be 'comfortable' with the condition/cue being tested and help to minimize between trial variation due to a 'learning effect'. Fortunately, the only variables which exhibited a main effect of trial were Dcm and I3%. In future studies, researchers may consider using more than two practice jumps to give the jumpers more opportunity to get 'comfortable' with the condition/cue being tested.

10.6. Pair-wise comparison of Non-cued Jumps Before and After the Cued Jumps

Several studies have demonstrated that vertical jump height decreases with fatigue (Smilios, 1998; Rodacki et al., 2002). To control for fatigue effects, this study allowed 45-60 seconds of rest between jumps. To further ensure subjects were not fatigued, a non-cued jump was performed after the cued conditions. A pair-wise comparison of non-cued jumps performed before and after the cued conditions demonstrated no significant ($P<0.05$) differences in jump height.

10.7. Practical Applications of This Study

This study has demonstrated that vertical jump performance can be described using a multitude of variables which can be calculated based on force-time data from a force platform. We have also demonstrated that the variables measured can help to provide a detailed description of vertical jump dynamics which in turn can help provide researchers and coaches with a better understanding of vertical jump performance.

Most people associate vertical jump performance with the measure of vertical jump height. Jump height remained the same for all conditions, but jump height is not the only variable that can be classified as a jump performance variable. The time between initiation of the countermovement and when the jumper starts to lift off the platform (Ttotal) can also be classified as a performance variable. Ttotal decreased for the cue DDF which means that the jumper was able to reach peak height in a shorter amount of time effectively improving his/her response time. An improved response time can have important implications for sport performance. For example, if a volleyball player is able to jump up to a given height faster to block or a basketball player can jump up faster to get a rebound this would be a performance advantage.

A few speculative conclusions can be drawn from the fact that jump height did not change despite changes in the vertical jump dynamics/technique. It is possible that we simply did not use the appropriate cues to elicit a change jump height. Another possibility is that no matter what cue was used jump height would still remain the same for all jumps. If jump height remained the same, independent of all cues, it can be inferred that each individual is only capable of producing a finite amount of impulse during the push-off independent of the jump technique/dynamics. If this is true then a training program should not focus on jump technique, but rather focus on training the neuromuscular system specifically to improve the impulse producing capability of the muscles.

This study has shown that the speed of the countermovement can be increased compared to the non-cued condition while jump height remains the same. It is of interest to researchers and coaches to determine if the opposite is also true. For example, we would like to determine how slow the countermovement can be while maintaining jump height. A slower countermovement would result in lower ground reaction forces (Av=0) and less loading of the muscles at the transition point from countermovement to push-off when velocity is momentarily zero. A very short countermovement can often be seen in volleyball players when starting a jump from a stationary squatted down 'ready' position. A short countermovement would also result in a relatively low Av=0 when compared to a countermovement from an upright standing position. At the beginning of a squat jump the acceleration (Av=0) is zero. It has been documented in the literature that countermovement jump height is greater than squat jump height (Bobbert et al., 1996; Komi & Bosco, 1978). Logically, it follows that there must be a critical point at which jump height decreases as the speed of the countermovement decreases. It would be helpful to determine if the abbreviated countermovement performed by volleyball players helps them jump higher or are they sacrificing valuable response time by performing the countermovement and experiencing little or no benefit in the way of increased jump height.

With the cue DDF, the speed of the countermovement increased and there was a shift in impulse production earlier in the push-off. If the countermovement is preformed slower than during the non-cued condition it is suspected that there would be a shift in impulse production to the last part of the push-off while jump height is maintained.

10.8. Future Studies

This study is one of the first in a progression of studies, which utilizes the ability to calculate a multitude of different profiles based on force-time data obtained from a force platform. Ultimately we are interested in improving our understanding of vertical jump performance and the effect that cues or "thought content" have on vertical jump performance.

We may have simply not used the appropriate cue that would increase jump height. It is possible that some other cue or combination of cues would lead to increased jump height. For example, if the jumper were told to 'Drop Down Fast & Explode From Bottom' at the same time they may have jumped higher. It would be helpful to know how other cues affect jump technique and if other cues increase jump height

It is of interest to see if SJ dynamics can be significantly altered with cues. Since push-off time is relatively short and the jumpers muscles are starting with a relatively low muscular tension (e.g., not pre-loaded) the rate of force development of the primary movers would be much more critical in determining jump dynamics. The total time of the jump for a SJ is less than the total time of a CMJ because there is only the push-off phase for the SJ. During a SJ the jumper doesn't have as much time to change his/her technique since there is no countermovement.

In this study, significant changes in jump technique were measured while jump height remained unchanged. Changes in the dynamic variables originated during the countermovement phase and continued into the push-off phase. In addition to CMJ dynamics, it is of interest to researchers to determine if jump height remains the same despite changes in jump technique when performing a SJ (e.g., no countermovement) when cues are used. If jump height remained the same despite changes in technique when no countermovement was performed, these finding would be in agreement with the findings of this study. This would provide further evidence that jump technique is not as important as once thought and that the force producing characteristics of the muscles are more important than technique.

Further investigation of the effect of other cues, instructions, arm swing, elimination of countermovement, state of training, fitness level, gender, testing of elite athletes from different sports and fatigue are some of the conditions that could be examined in relation to vertical jump performance.

If an optimum jump performance profile can be determined, then immediate biofeedback regarding the performance of a jump may be used so that the jumper can perform the successive jumps to more closely match the ideal jump technique. It is also possible that specific cues could be used to change the dynamics of the vertical jump to improve performance.

11. CONCLUSION

From our results we can state that the cues DDF and EFB had an effect on CMJ dynamics and that jump height was not affected by any of the cues. We failed to support our null hypothesis that non-cued and cued CMJ have equivalent techniques. However, our second hypothesis which stated that non-cued and cued CMJ have equivalent jump heights was confirmed. This study has clearly demonstrated that the cues DDF and EFB have an effect on jump technique but none of the cues studied effect jump height.

The cue DDF resulted in a slightly faster response time that was attributed to a faster countermovement. The cue EFB resulted in a slightly faster and deeper countermovement. The time saved during the faster countermovement was lost since the jumper performed a deeper countermovement. The cue POT did not have any significant effects on jump technique or jump height when compared to a non-cued jump. In summary, the cue DDF was the only cue that improved jump performance by decreasing response time.

This study shows that different jump techniques can be used to achieve the same maximal jump height. Jump height remained the same as technique changed. Training that leads to neuromuscular adaptations that improve the strength of the primary muscle groups used in vertical jumping may be more beneficial than training time to 'optimize' jump technique.

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APPENDIX A

Physical Activity Readiness Questionnaire - PAR-Q (revised 1994)

PAR - Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?
☐	☐	2.	Do you feel pain in your chest when you do physical activity?
☐	☐	3.	In the past month, have you had chest pain when you were not doing physical activity?
☐	☐	4.	Do you lose your balance because of dizziness or do you ever lose consciousness?
☐	☐	5.	Do you have a bone or joint problem that could be made worse by a change in you physical activity?
☐	☐	6.	Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
☐	☐	7.	Do you know of <u>any other reason</u> why you should not do physical activity?

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want—as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active -- begin slowly and build up gradually - This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever — wait until you feel better; or
- if you are or may be pregnant— talk to your doctor before you start becoming more active.

Please note: If your health changes so that you then answer [illegible] any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

<u>Informed Use of the PAR-Q:</u> The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

You are encouraged to copy the PAR-Q but only if you use the entire form

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

NAME ____

SIGNATURE ____ DATE ______________________________

SIGNATURE OF PARENT ____ WITNESS ______________________________
or GUARDIAN (for participants under the age of majority)

Supported by: Health Canada Santé Canada

APPENDIX B

APPROVAL CERTIFICATE

17 October 2002

TO: Jason Driedger
Principal Investigator

FROM: Lorna Guse, Chair
Education/Nursing Research Ethics Board (ENREB)

Re: Protocol #E2002:075
The Effect of Verbal Cues on Vertical Jump Performance"

Please be advised that your above-referenced protocol has received human ethics approval by the Education/Nursing Research Ethics Board, which is organized and operates according to the Tri-Council Policy Statement. This approval is valid for one year only.

Any significant changes of the protocol and/or informed consent form should be reported to the Human Ethics Secretariat in advance of implementation of such changes.

APPENDIX C

Eq#	Equation	Variables
1	$F = ma$	F = force [N] m = mass [kg] a = acceleration [$m \cdot s^{-2}$]
2	$F_{bw} = mg$	F_{bw} = force due to mass of the jumper m = mass of jumper [kg] g = acceleration due to gravity = 9.81 [$m \cdot s^{-2}$]
3	$F_{net} = F_{measured} - F_{bw}$	F_{net} = net force [N] $F_{measured}$ = ground reaction for measured by the force platform [N] F_{bw} = force due to the mass of the jumper [N]
4	$a_{net} = (F_{measured} - F_{bw}) / m$	a_{net} = net acceleration [$m \cdot s^{-2}$] $F_{measured}$ = ground reaction for measured by the force platform [N] F_{bw} = force due to the mass of the jumper [N] m = mass of jumper [kg]
5	$v_2 = v_1 + a_{net} \cdot \Delta t$	v = velocity [$m \cdot s^{-1}$] a_{net} = net acceleration [$m \cdot s^{-2}$] Δt = change in time [s]
6	$d_2 = d_1 + v_1 * \Delta t + ½\, a_{net} \Delta t^2$	d = displacement [m] v = velocity [$m \cdot s^{-1}$] Δt = change in time [s]
7	$I_2 = I_1 + m \cdot a_{net} \cdot \Delta t$	I = impulse [N s] a_{net} = net acceleration [$m \cdot s^{-2}$] m = mass of jumper [kg] Δt = change in time [s]
8	$V_{apex} = I_{apex} / m$	V_{apex} = maximum velocity [$m \cdot s^{-1}$] I_{apex} = maximum impulse [N s] m = mass of jumper [kg]
9	$h = (½\, v_{apex}^2)/g$	h = jump height [m] g = acceleration due to gravity = 9.81 [$m \cdot s^{-2}$] Δt = flight time [s]

APPENDIX D

Table. Mean ± SD of each variable and the associated condition. Values which differ significantly from the non-cued condition are marked (*P<0.05, **P<0.01).

	Variable	Units	non-cued	DDF	EFB	POT
COUNTERMOVEMENT	Dcm	cm	-35.7 ± 7.8	-37.6 ± 8.4	-39.2 ± 7.6**	-37.1 ± 8.5
	Tcm	s	0.69 ± 0.01	0.62 ± 0.16**	0.71 ± 0.16	0.71 ± 0.16
	Vnadir	$m \cdot s^{-1}$	-1.07 ± 0.2	-1.36 ± 0.28**	-1.18 ± 0.23**	-1.13 ± 0.24
	AVnadir	$m \cdot s^{-2}$	-0.06 ± 0.06	-0.11 ± 0.12**	-0.07 ± 0.07	-0.06 ± 0.05
	Anadir	$m \cdot s^{-2}$	-5.04 ± 1.52	-7.2 ± 1.87**	-5.62 ± 1.7*	-5.38 ± 1.56
	VAnadir	$m \cdot s^{-1}$	-0.51 ± 0.18	-0.62 ± 0.18**	-0.57 ± 0.17	-5.44 ± 0.16
PUSH-OFF	Tpo	s	0.31 ± 0.05	0.31 ± 0.06	0.32 ± 0.06	0.31 ± 0.06
	Av=0	$m \cdot s^{-2}$	11.51 ± 2.35	13.55 ± 3.14**	12.05 ± 2.99	11.64 ± 3.07
	Aapex	$m \cdot s^{-2}$	13.02 ± 2.05	14.39 ± 2.62**	13.23 ± 2.3	13.34 ± 2.63
	VAapex	$m \cdot s^{-1}$	0.98 ± 0.92	0.4 ± 0.76**	0.73 ± 0.92	0.92 ± 0.93
	I1%	%	36.2 ± 3.6	39.3 ± 5.2**	38.2 ± 5.8**	37.1 ± 5.5
	I2%	%	33.7 ± 3.5	32.3 ± 4**	32 ± 4.9*	33 ± 5.2
	I3%	%	30.1 ± 4.3	28.4 ± 4.7**	29.8 ± 4.3	29.9 ± 4.8
	Ttotal	s	1 ± 0.16	0.92 ± 0.02**	1.03 ± 0.2	1.02 ± 0.2
	JH	cm	40.2 ± 5.7	39.7 ± 6	40.4 ± 5.6	39.6 ± 6

*P<0.05, **P<0.01

APPENDIX E

To determine if the order of the cues had an effect, a one-way ANOVA was performed on the dynamic variables which were affected most by the cues (Table 1E). A Tukey's post hoc analysis was then performed to determine between which groups (i.e., 1^{st}, 2^{nd}, 3^{rd}) the difference occurred (Table 2E). For example, Table 2E shows that Anadir was significantly (P<0.05) greater in magnitude for group 3 when compared to group 2. Group 3 (the group that received the cue POT last) had a greater downward acceleration during the countermovement.

Table 1E. F Statistics (one-way ANOVA) of select dynamic variables to determine if there was an order of cue effect. (*P<0.05, $^@$P<0.06)

	Anadir	Vnadir	Av=0	I1%
DDF	0.158	0.421	1.395	1.55
EFB	0.046	0.331	0.004	0.375
POT	3.298*	4.489*	$3.265^@$	4.87*

Table 2E. Mean difference between groups that got the cue POT 1^{st}, 2^{nd}, and 3^{rd} for select dynamic variables. Tukey's post hoc analysis was used. (*P<0.05)

	Anadir	Vnadir	Av=0	I1%
2 vs. 1	0.53	-0.03	-0.82	0.47
3 vs. 1	-0.88	-0.24*	2.01	5.61^*
3 vs. 2	-1.42^*	-0.20	2.84^*	5.14^*

Further analysis was performed to determine if the group of n=12 subjects that received the cue POT skewed the results. The subjects that received the cue POT last were removed from the data set. The results of the analysis show that there were similar changes in the data and that the group that received the cue POT last did not skew the data (Table 3E and Table 4E).

Table 3E. F Statistics (RM ANOVA) of select dynamic variables for subjects (n=24) which did not receive the cue POT last. (*P<0.05; **P<0.01 #P<0.001)

		Dynamic Variables				
		Anadir	Vnadir	I1%	Av=0	JH
Effect	Cue	**20.95#**	**13.97#**	**9.14#**	**9.02#**	0.136
	Trail	0.56	1.32	0.66	0.35	0.285
	Cue x Trial	0.92	0.34	0.83	1.28	0.479

Table 4E. Mean ± SD of select dynamic variables for subjects (n=24) which did not receive the cue POT last. Values which differ significantly from the non-cued condition are marked. Tukey's post hoc analysis was used. (*P<0.05, **P<0.01).

Variable	Units	non-cued	DDF	EFR	POT
Anadir	m·s-2	-4.80	-6.797**	-5.583*	-5.00
Vnadir	m·s-1	-1.03	-1.289**	-1.16**	-1.06
Av=0	m·s-2	11.24	13.02**	11.51	10.84
I1%	%	35.30	37.9**	36.80	35.30

APPENDIX F

Pearson Correlation and Stepwise Linear Regression Analysis

Table 1F. Summary of Pearson correlation.

	JH	Ttotal
Subject	-0.063	-0.062
Cue	-0.02	0.099*
Repetition	-0.014	0.002
Group - order	0.145**	-0.114*
JH	1	0.035
Ttotal	0.035	1
Tcm	0.073	0.966**
Tpo	-0.078	0.723**
I1%	-0.087	-0.334**
I2%	-0.017	-0.305**
I3%	0.116*	0.681**
Anadir	0.004	0.562**
Avnadir	-0.041	0.360**
Aapex	0.238**	-0.512**
Av=0	0.147**	-0.589**
Vnadir	-0.186**	0.374**
Vanadir	-0.221**	0.233**
Vaapex	0.096*	0.218**
Dcm	-0.327**	-0.508**
Height	-0.019	0.231**
Mass	0.025	0.132**
BMI	0.045	-0.034
Age	0.238**	-0.141**
Inseam	0.126*	0.200**

*P<0.05, **P<0.01

Table 1F shows that Aapex, Av=0, Vnadir, Vanadir, and Dcm are positively correlated ($P<0.01$) with jump height. For example, higher jumpers had greater Dcm, Aapex and Av=0. This demonstrates that higher jumpers had a deeper countermovement and that the GRF produced at the bottom of the countermovement and start of the push-off phases where greater than the low jumpers. In order to produce greater GRF the jumper must be able to contract the primary movers (i.e., knee and hip extensors) more forcefully than the lower jumpers. Logically, it makes sense that higher jumpers are indeed 'stronger' than lower jumpers.

There was also a high correlation between total time (Ttotal) and many of the variables. For example, a greater percentage of total impulse is produced during the last third of the push-off phase (I3%) during jumps that take more time. The negative correlation between Ttotal and Aapex and Av=0 also illustrates this point.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
a.	.708(a)	.501	.500	.14013
b.	.772(b)	.596	.594	.12623
c.	.827(c)	.684	.682	.11180
d.	.847(d)	.717	.713	.10605
e.	.846(e)	.716	.714	.10604
f.	.857(f)	.734	.731	.10270
g.	.861(g)	.742	.738	.10144
h.	.863(h)	.745	.741	.10083
i.	.866(i)	.749	.744	.10021
j.	.868(j)	.753	.747	.09960
k.	.872(k)	.761	.755	.09804
l.	.876(l)	.767	.761	.09690

a Predictors: (Constant), I3%
b Predictors: (Constant), I3%, Anadir
c Predictors: (Constant), I3%, Anadir, Dcm
d Predictors: (Constant), I3%, Anadir, Dcm, Vnadir
e Predictors: (Constant), I3%, Dcm, Vnadir
f Predictors: (Constant), I3%, Dcm, Vnadir, VAapex
g Predictors: (Constant), I3%, Dcm, Vnadir, VAapex, Mass
h Predictors: (Constant), I3%, Dcm, Vnadir, VAapex, Mass, JumpHeight
i Predictors: (Constant), I3%, Dcm, Vnadir, VAapex, Mass, JumpHeight, VAnadir
j Predictors: (Constant), I3%, Dcm, Vnadir, VAapex, Mass, JumpHeight, VAnadir, Aapex
k Predictors: (Constant), I3%, Dcm, Vnadir, VAapex, Mass, JumpHeight, VAnadir, Aapex, Av=0
l Predictors: (Constant), I3%, Dcm, Vnadir, VAapex, Mass, JumpHeight, VAnadir, Aapex, Av=0, Order Group

Table 2F. Stepwise linear regression with dependent variable Ttotal.

A stepwise linear regression revealed that I3% is predictive of Ttotal (adjusted $R^2 = 0.500$) Table 2F. This is congruent with the high Pearson correlation between Ttotal and I3% in Table 1F. With a greater percentage of total impulse occurring during the last third of the push-off phase less impulse must be produced at the beginning of the push-off phases. If less impulse is being produced at the beginning of the push-off phase then the jumper is not accelerating as much at the beginning of the push-off and therefore the push-off phase takes longer. There is a negative correlation between Ttotal and Av=0 illustrated in Table 1F. Decreased Av=0 results from a slower countermovement (Tcm).

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
A	.361(a)	.131	.128	.05647
B	.568(b)	.322	.318	.04993
C	.657(c)	.432	.427	.04577
D	.690(d)	.476	.470	.04403
E	.735(e)	.540	.534	.04129
F	.761(f)	.579	.572	.03956
G	.768(g)	.590	.582	.03910

a Predictors: (Constant), Dcm
b Predictors: (Constant), Dcm, Tpo
c Predictors: (Constant), Dcm, Tpo, VAapex
d Predictors: (Constant), Dcm, Tpo, VAapex, Aapex
e Predictors: (Constant), Dcm, Tpo, VAapex, Aapex, I2%
f Predictors: (Constant), Dcm, Tpo, VAapex, Aapex, I2%, Subject
g Predictors: (Constant), Dcm, Tpo, VAapex, Aapex, I2%, Subject, BMI

Table 3F. Stepwise linear regression with dependent variable JumpHeight.

Table 3F illustrates that a large number of variables must be used in the model in order to effectively predict jump height.