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Net Impulse and Net Impulse Characteristics in Vertical Jumping

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A dissertation

presented to

the faculty of the Department of Kinesiology, Leisure, and Sport Sciences

East Tennessee State University

In partial fulfillment

of the requirements for the degree

Doctor of Philosophy in Sport Physiology and Performance

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by

Satoshi Mizuguchi

August 2012

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Craig A. Wassinger, Ph.D.

Keywords: Vertical Jump, Net Impulse, Athlete's Performance Monitoring

## ABSTRACT

### Net Impulse and Net Impulse Characteristics in Vertical Jumping

by

Satoshi Mizuguchi

The purpose of this dissertation was to explore the potential use of net impulse and its characteristics in vertical jumping to monitor athletes' performance status and responses/adaptations to interventions. Five variables were proposed as net impulse characteristics: net impulse height and width, rate of force development, shape factor, and net impulse proportion. The following were then examined: 1) test-retest reliability of a new approach to identify net impulse in a force-time curve and of net impulse characteristics and criterion validity of the new approach: 2) effective measures of net impulse characteristics: 3) relationships between training-induced changes in its characteristics and force production ability. The following are major findings of the dissertation. Rate of force development particularly for the countermovement jump require a large magnitude of change to overcome the variable's inherent variability. Shape factor and net impulse proportion for the static jump should be used with caution and requires further investigations. Alternative net impulse can be used interchangeably to criterion net impulse. Of the proposed net impulse characteristics, net impulse height and width and shape factor were found to contribute to countermovement jump height, whereas all the net impulse characteristics were found to contribute to static jump height. Of the characteristics found to contribute, relative net impulse height (net impulse height divided by system mass) appears to be an important characteristic to achieve a high jump height for the countermovement and static jumps and net impulse proportion for the static jump. A mechanism behind increased countermovement jump height may be an increased countermovement

displacement as a result of increased force production ability. A mechanism behind increased static jump height is the increased proportion of the entire positive impulse occupied by net impulse (i.e. increased net impulse proportion). The findings of this dissertation show the possibility of the use of the net impulse characteristics to monitor athletes' performance status and responses/adaptations to interventions. However, because this dissertation was the first to explore the potential use of the net impulse characteristics for athletes' performance monitoring, the existing knowledge is still preliminary and further research is required before practical recommendations are made.

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## DEDICATION

I would like to dedicate this dissertation to my family - Mayako Mizuguchi, Takeru Mizuguchi, and Akari Mizuguchi. I would also like to dedicate this work to competitive sports.

## ACKNOWLEDGEMENTS

I would like to thank the following people:

Dr. Michael H. Stone for everything

Dr. Hugh S. Lamont for encouragements and sharing his office space

Dr. William A. Sands for his tremendous assistance with this dissertation

Dr. Craig A. Wassinger for his support and serving as a committee member

I would also like to thank all my friends for their support and East Tennessee State University Men's Soccer Team for participating in this dissertation.

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## CHAPTER 1

### INTRODUCTION

#### Introduction

Jumping is a common activity in sports and a training mode used in athletic settings in an attempt to improve explosive performance. It is also used as a test of lower extremity explosiveness. The performance of vertical jumping has been correlated to many other explosive movements (Carlock et al., 2004; Nuzzo, McBride, Cormie, & McCaulley, 2008; Peterson, Alvar, & Rhea, 2006). Vertical jumping can be used as a simple, easy, quick, and less-fatiguing method of assessment for the lower extremity explosiveness and requires minimal familiarization (Moir, Button, Glaister, & Stone, 2004; Moir, Sanders, Button, & Glaister, 2005). Thus, it has high potential to be used frequently to assess one's explosive performance state (e.g. training adaptations, tapering, overreaching and overtraining, and injury rehabilitation). In addition, it could be improved by strength training and/or power training, which relies on different physiological adaptation mechanisms (Ahtiainen, Pakarinen, Alen, Kraemer, & Hakkinen, 2003; Cormie, McGuigan, & Newton, 2010a; Hakkinen et al., 1998; Winchester et al., 2008). However, the simple measurements of jump height and peak power, which are two commonly measured variables, may not always be sufficient to provide insight into mechanisms that comprise one's explosive performance state. In fact, Cormie and colleagues (2010a; 2010d) have reported that strength and power training and an individual's initial strength level all led to different training-induced changes in force-time curves as well as kinetic and kinematic variables and neuromuscular and muscle morphological characteristics.

When an athlete applies a force to produce a movement, the force is never applied instantaneously. Rather, it is applied over a certain length of time. Impulse, which accounts for

the time length of force application, is the product of force and time in the simplest term. In vertical jumping net impulse is part of a total impulse that leads to the projection of the body into the air. Thus, net impulse can be regarded as a kinetic equivalence of jump height when it is considered in relation to body mass. By constructing a force-time curve and identifying key time points during a vertical jump, it is possible to identify which part of a force-time curve is equivalent to a net impulse. This procedure reveals the shape of a net impulse in addition to a number of other potential variables that are expected to characterize a net impulse in such a way that they collectively lead to the formation and expression of the net impulse observed. Some examples of net impulse characteristics include rate of force development (Sands, McNeal, & Shultz, 1999), shape factor (Dowling & Vamos, 1993), net impulse height (peak force minus system weight), and net impulse width (time span of a net impulse).

There have been studies that examined net impulse as one of the variables of interest (Bosco & Komi, 1979; Khamoui et al., 2009; Ugrinowitsch, Tricoli, Rodacki, Batista, & Ricard, 2007). However, few studies have reported what changes take place in net impulse characteristics and how the changes influence net impulse as a result of an intervention. By studying changes in net impulse and its characteristics, it may be possible to identify signs of adaptations to different types of training and mechanisms behind changes in one's jump performance (i.e. lower extremity explosiveness). This, in turn, may further allow the test of vertical jumping to provide more information when monitoring performance changes. For example, Cormie and colleagues (2008, 2009, 2010a, 2010c, 2010d) conducted a series of studies that examined changes in force-time curves in the countermovement jump. In one of their studies (Cormie et al., 2010a), they found that power training led to an increase in the velocity of the countermovement perhaps in an attempt to take greater advantage of the stretch-shortening



cycle. This finding was supported by a second study by Cormie and colleagues (Cormie et al., 2010c). Another finding from the first study was that power training caused the whole countermovement jump to be performed more quickly while a greater amount of force was still produced (Cormie et al., 2010a). These data have important implications for a number of sport activities. For example, strength and power training may alter the stretch-shortening cycle such that greater acceleration and peak velocity may be achieved in sprinting. Based on these interpretations of the results, examination of variables related to rate of force development and net impulse width may provide information on the aspect of acceleration and stretch-shortening cycle function. In another study (Cormie et al., 2010d), it was found that a greater initial strength level positively influenced net impulse height, even after only a few weeks of training. Simultaneously, the results showed greater acceleration early in sprinting (first 10 meters) and a quicker manifestation of the jump training adaptation in other movements such as sprinting (i.e. stronger individuals showed a statistically significant decrease in sprint time at five weeks while weaker individuals did not show an improvement until 10 weeks). In addition, strength training (or having the background of strength training) seemed to increase the magnitude of the second peak (See Figure 2.1 in Chapter 2). Based on these previous observations, examination of net impulse height and a change in the magnitude of the second peak may provide information on the aspect of strength.

Thus, the purpose of this dissertation was to explore the potential use of net impulse and its characteristics in vertical jumping to monitor athletes' performance status and responses/adaptations to interventions. In order to fulfill the purpose, the following were examined: 1) test-retest reliability of a new approach to identify net impulse in a force-time curve and net impulse characteristics and criterion validity of the new approach: 2) effective

measures of net impulse characteristics: 3) relationships between training-induced changes in net impulse and net impulse characteristics and between changes in the characteristics and force production ability.

### Operational Definitions

1. Amortization phase: the phase during the countermovement jump in which transition from the countermovement and the propulsion occurs.
2. Between-session difference (test-retest reliability): the degree to which measurements from two or more sessions agree in terms of measured values within individuals.
3. Countermovement jump (CMJ): a type of vertical jumps performed with a preliminary countermovement.
4. Countermovement: a preliminary downward movement performed prior to the initiation of the propulsion phase in the countermovement jump.
5. Countermovement-stretching phase: a phase of the countermovement jump during which vertical ground reaction force exceeds system weight while a jumper is transitioning to the propulsion-acceleration phase.
6. Countermovement-unweighting phase: a phase of the countermovement jump during which vertical ground reaction force is below system weight.
7. Criterion validity: the degree to which separate measures of the same property agree
8. Entire positive impulse: all positive impulses combined, which consist of positive impulses during the countermovement-stretching and propulsion-acceleration phases for the countermovement jump and of a positive impulse during the propulsion-acceleration phase for the static jump.

9. Flight time: length of time during which a jumper is in the air (i.e. time between take-off and landing).
10. Force production ability: an individual's ability to produce force, examples of which are isometric peak force and rate of force development.
11. Force-time curve: a graph representing measured vertical ground reaction force with time on the X axis and vertical ground reaction force on the Y axis.
12. Heteroscedasticity: presence of a relationship between the magnitude of a measured value and the degree of error in which as the magnitude of a measured value of a variable becomes greater, the error or difference between two measurements of the variable or two measurements of two variables being compared becomes greater (Atkinson & Nevill, 1998).
13. Isometric mid-thigh pull: a multi-joint isometric test performed in the power position of the clean with an intention to pull as fast and hard as possible.
14. Isometric peak force: the highest instantaneous force value measured during isometric mid-thigh pull.
15. Isometric rate of force development (time-dependent isometric mid-thigh pull variable): a change in isometric force divided by the time duration over which the change in isometric force occurs during isometric mid-thigh pull.
16. Isometric time-dependent force: isometric instantaneous forces at or rates of force development over a specific time.
17. Jump height: a vertical displacement of the center of system mass from take-off to the apex of the flight.
18. Negative impulse: impulse observed below system weight in a force-time curve.

19. Net impulse characteristics: characteristics of a vertical jump force-time curve that are related to net impulse. Changes in these characteristics are thought to influence net impulse.
20. Net impulse height: height of net impulse identified on a force-time curve and calculated as peak force minus system weight.
21. Net impulse proportion: a proportion of net impulse to the entire positive impulse and calculated by net impulse divided by the entire positive impulse multiplied by one hundred.
22. Net impulse width: a time span of net impulse identified in a force-time curve.
23. Net impulse: a summation of all positive and negative impulses.
24. Normalization of a force-time curve: subtraction of system weight from a force-time curve such that force is nearly zero, if not zero, while an individual is standing still on a force plate.
25. Positive impulse: impulse observed above system weight in a force-time curve.
26. Propulsion-acceleration phase: a phase of the countermovement and static jumps during which vertical ground reaction force is above system weight while a jumper is extending the hip and knee joints and plantar-flexing the ankle joint to push off into the air.
27. Propulsion-deceleration phase: a phase of the countermovement and static jumps during which vertical ground reaction force is below system weight while a jumper is no longer producing force greater than system weight and thus gravity has already begun to reduce vertical velocity gained during the propulsion-acceleration phase.
28. Rank-order relationship (test-retest reliability): the degree to which relative positions (ranks) of individuals with respect to measurement scores are consistent.

29. Rate of force development (net impulse characteristic): calculated as a change in force divided by the time duration over which the change in force occurs during the countermovement-stretching phase for the countermovement jump and from the beginning to maximum force of the propulsion-acceleration phase for the static jump.
30. Relative net impulse height: net impulse height divided by system mass.
31. Shape factor: a ratio of net impulse to a rectangle shape formed around the net impulse identified in a force-time curve.
32. Static jump (SJ): a type of jumps performed from a static squat position without any countermovement.
33. System mass: body mass of an individual and external mass due to clothes, shoes, etc.
34. System weight: force created by the effect of gravity on system mass.
35. Systematic bias: a shift in values of the same measurement under the same conditions across two or more sessions.
36. Take-off velocity: vertical velocity at take-off and calculated by net impulse divided by system mass when the initial velocity is zero.
37. Take-off: a point during a vertical jump at which the feet completely leave the ground.
38. Test-retest reliability: the degree to which repeated measurements of the same variable agree
39. The first peak (of the countermovement jump force-time curve): the initial one of two peaks frequently observed in the countermovement jump force-time curve.
40. The second peak (of the countermovement jump force-time curve): the second one of two peaks frequently observed in the static jump force-time curve.

## CHAPTER 2

### COMPREHENSIVE REVIEW OF LITERATURE

Vertical jumping is a common mode of testing used in sport science to assess one's explosiveness of the lower extremity (Carlock et al., 2004; Cormie, McGuigan, & Newton, 2009; Cormie et al., 2010a; Cormie, McGuigan, & Newton, 2010b; Cormie et al., 2010d; McBride et al., 2009; Nuzzo et al., 2008; Peterson et al., 2006). It is easy, involves minimum risk to perform, and requires minimum familiarization (Moir, Shastri, & Connaboy, 2008; Moir, Garcia, & Dwyer, 2009). It can also be manipulated to assess explosiveness under different levels of resistance (Cormie, McCaulley, & McBride, 2007; Hakkinen, Komi, & Kauhanen, 1986), may allow for the assessment of some aspect of one's stretch-shortening cycle function (Lloyd, Oliver, Hughes, & Williams, 2011), and is often a direct measurement of performance in sports involving jumping such as volleyball and basketball.

Due to its usefulness, advancement of measurement and analytical techniques of vertical jump performance could benefit sports scientists with respect to athletes' performance monitoring and understanding of training adaptations. One such a way to provide benefit could be the identification of a net impulse in a force-time curve and net impulse characteristics. Although few studies have investigated vertical jumping from the perspective proposed in this dissertation, previous studies have measured net impulse and characteristics of a force-time curve (Bosco & Komi, 1979; Cormie et al., 2009; Cormie et al., 2010a, 2010d; Dowling & Vamos, 1993; Sands et al., 1999; Ugrinowitsch et al., 2007). In addition, it is important to understand rationale for the use of vertical jumping as a method to assess one's lower extremity explosiveness because this understanding forms the basis of implementing a vertical jump test. Therefore, the purposes of this literature review are to explore 1) rationale for the use of vertical

jumping as a method to assess one's lower extremity explosiveness, 2) the measurements of force-time curve characteristics and net impulse, and 3) training-induced changes in force-time curves.

### Rationale for a Vertical Jump Assessment

Jumping ability has been shown to have a strong correlation with many other fundamental explosive movements performed in sports and with the lower extremity maximum strength (Carlock et al., 2004; Nuzzo et al., 2008; Peterson et al., 2006). For instance, Peterson et al. reported a strong correlation between jump height and sprint, agility, and squat 1RM performance (Peterson et al., 2006). Although a correlation does not determine a cause-and-effect relationship, three primary factors can explain the reported relationships. These are the application of vertical force, neuromuscular characteristics, and the stretch-shortening cycle.

From a biomechanical standpoint, in order to optimize vertical jumping performance, produced force should be directed as vertically to the ground as possible. If produced force is not directed vertically, the resulting jump will contain horizontal displacement proportional to the magnitude of the horizontal force (Hall, 2007b). Interestingly, in other explosive movements that seem more horizontal, vertical force has still been reported to be a key factor (Chow & Hay, 2005; Guido, Werner, & Meister, 2009; Kellis, Katis, & Gissis, 2004; Pucsok, Nelson, & Ng, 2001; Ridderikhoff, Batelaan, & Bobbert, 1999; Wallace, Kernozek, & Bothwell, 2007; Werner et al., 2005; Weyand, Sandell, Prime, & Bundle, 2010; Weyand, Sternlight, Bellizzi, & Wright, 2000; Yu, Broker, & Silvester, 2002). For instance, Weyand, Sandell, Prime, and Bundle and Weyand, Sternlight, Bellizzi, and Wright (2010; 2000) have reported in a series of studies that vertical force production is as important, if not more, as horizontal force for top in sprinting, even though it appears to rely more on horizontal force production. In the long jump, it has been

reported through computer simulation that increases in both approach velocity and vertical force are the primary determinants of long jump distance (Chow & Hay, 2005). In other movements such as instep kicking in soccer and windmill pitching in softball, vertical ground reaction force production has been reported to be much greater than horizontal force production, suggesting a potentially large contribution of vertical force to the performance of these movements (Guido et al., 2009; Kellis et al., 2004).

With respect to neuromuscular characteristics, neuromuscular activation pattern in dynamic explosive movements (dynamic ballistic and semi-ballistic movements performed with maximum effort to accelerate) have been shown to be different from non-explosive movements (non-ballistic movements without maximum effort to accelerate) (Behm & Sale, 1993; Komi, 2003; Zehr & Sale, 1994). In particular, firing frequency and synchronization of motor units have been reported to be greater in explosive movements (Komi, 2003). In addition, adaptations through explosive training have been shown to be different from non-explosive training (Cormie et al., 2010a; Hakkinen, Komi, & Alen, 1985). Cormie et al. (2010a) compared heavy squat training to jump training and used vertical jumping as one of the tests to measure training outcome. Their results showed that the jump training group showed an increase in rate of force development in the countermovement jump simultaneously with an increase in rate of electromyographic rise during the countermovement jump while the squat training group did not show any changes at five weeks into training.

In addition to neuromuscular activation pattern, muscle fiber type composition and architecture are also related to vertical jump performance. Bosco and Komi (1979) reported that in both the countermovement jump and static jump, jump height and net impulse among others had statistically significant positive correlations with the percentage of fast twitch muscle fibers



in the vastus lateralis. Furthermore, Cormie et al. (2010a) also reported an increase in muscle pennation angle without changes in anatomical muscle cross sectional area in the jump training group as early as 5 weeks into training. In this study, an improvement was also reported in sprint performance as a result of the jump training.

The countermovement and static jumps are two commonly used types of jump in a vertical jump test. These two types of jump represent the types of muscle contraction commonly used in sports. A key difference between these two jumps is the use of the stretch-shortening cycle. The countermovement jump involves the use of the stretch-shortening cycle while the static jump involves much less. The stretch-shortening cycle is a mechanism of coordinating muscle contractions, in which a whole muscle-tendon unit (muscle fibers and tendon) undergoes a brief stretch prior to its shortening. The stretch-shortening cycle has been shown to enhance joint torque production and thus the resultant performance (Finni, Ikegawa, & Komi, 2001; Leonard, DuVall, & Herzog, 2010; Rassier, 2009). There are four proposed mechanisms by which the enhancement of performance is realized. These are time to develop force, stored elastic energy, pre-stretch potentiation, and stretch reflex (Enoka, 2008). Movements involving stretch-shortening cycle allow for time to develop force to a higher level than otherwise possible prior to the beginning of muscle shortening because of the eccentric phase. In fact, in vertical jumping, Bobbert and colleagues (1996, 2005) have reported that the time to develop force during the countermovement phase (greater active state or proportion of cross-bridges: thus greater force at the beginning of the propulsion phase) was the primary reason for greater jump height in the countermovement jump compared to the static jump through computer simulation. Stored elastic energy is the amount of strain energy stored in the involved tissues due to a quick stretch. This stored elastic energy can be converted to kinetic energy and enhance overall force

production during muscle shortening (Anderson & Pandy, 1993). Although it is controversial whether muscle fibers are actually stretched immediately prior to the amortization phase, there seems to be an agreement that a tendon is actually stretched storing strain energy (Enoka, 2008; Kawakami, Muraoka, Ito, Kanehisa, & Fukunaga, 2002; Kurokawa, Fukunaga, & Fukashiro, 2001). Skeletal muscle fiber force production has been known to increase during and after the stretch if the muscle fibers are stretched while being activated (i.e. pre-stretch potentiation) (Rassier, 2009). Pre-stretch potentiation in vertical jumping can be speculated to be caused by a quick stretch of muscle fibers, which is thought to enhance the cross bridge formation and increase the stiffness of non-contractile protein in sarcomeres (Rassier, 2009). The enhancement of performance due to stretch reflex is the result of the activation of type Ia afferent pathway via the muscle spindles. Stretch reflex may contribute to the propulsion phase by enhancing the agonist force output and inhibiting the antagonists (Enoka, 2008; Kilani, Palmer, Adrian, & Gapsis, 1989).

In addition to the underlying mechanisms behind the relationships between vertical jump and other explosive movements, loading conditions can be manipulated to simulate different levels of resistance encountered in sports. McBride, Triplett-McBride, Davie, and Newton (2002) examined the effects of explosive jump training with different loads on vertical jump, sprint, and agility performance. The results of the study using minimally trained subjects showed that the group that trained with light load improved agility and sprint times while the group that trained with heavy load improved only agility time. Considering the possible difference in the levels of inertia to overcome between agility (quick change of direction) and sprint, these results suggests that performance adaptations may be specific to the level of resistance and consequent movement velocity in training. Moreover, Cormie et al. (2007) investigated the effect of power

training vs. power and strength training among minimally trained subjects on the lower extremity explosiveness assessed by the countermovement jump with loads ranging from body weight to 80kg. The power training group trained only with the body weight countermovement jump while the power and strength training group trained with both the countermovement jump and back squat. Their results showed that the power and strength training group was able to improve jump height at all loads while the power training group improved only from body weight to 40kg. Thus, the manipulation of loading condition in vertical jump testing may provide information about resistance training effectiveness and performance readiness for movements that have different profiles of resistance levels. In a subsequent investigation, the results of the study Cormie and colleagues (2010d) indicated that weak athletes will gain a greater improvement in power production by strength training alone compared to power training.

#### Impulse in Vertical Jumping

Impulse is a kinetic variable based on Newton's second law (Law of acceleration). This law may be stated as follows; *a force applied to a body causes an acceleration of that body of a magnitude proportional to the force, in the direction of the force, and inversely proportional to the body's mass* (Hall, 2007b). Mathematically, this can be expressed as follows:

$$\sum F = ma \text{ (Equation 1) (Enoka, 2008)}$$

where F is force, m is mass, and a is acceleration.

However, when an athlete applies a force to produce a movement, the force is never applied instantaneously. Rather, it is applied over a certain length of time. Because of this, an applied force must be considered in relation to the time length for which it is applied. The product of force and time is known as impulse. Mathematically, this can be expressed as follows:

$$I = \int_{t_1}^{t_2} F \Delta t \text{ (Equation 2) (Enoka, 2008)}$$

where  $I$  is impulse and  $\Delta t$  is change in time or time length. Graphically, an impulse can be represented as the area under a force-time curve of a movement.

By re-arranging the above equation of impulse, the following equation can be obtained.

$$\sum Ft = \Delta mv \text{ (Equation 3) (Enoka, 2008)}$$

where  $\Delta v$  is change in velocity. Because the left side of Equation 3 is impulse and the right side is momentum, Equation 3 is also known as the impulse-momentum relationship. From this relationship, it is clear that a change in the velocity of an object is directly related to impulse. In the case of vertical jumping initiated from a stationary position (zero velocity), an object is the body of an athlete and a change in the velocity is equivalent to the final velocity at take-off. Thus, the calculation of take-off velocity from an impulse is possible when the athlete's body mass (or system mass) is known. Moreover, the calculated take-off velocity can then be used to predict a jump height (vertical displacement from the take-off to the apex of the flight) using the laws of constant acceleration.

#### Force-Time Curve and Net Impulse

A force-time curve of a vertical jump has been studied at least since the 1970s. A force-time curve generally refers to a vertical force plotted against elapsing time. In vertical jumping, a force-time curve typically appears as in Figures 2.1 (countermovement jump) and 2.2 (static jump). Key time points and phases are indicated in the figures based on what previous studies have used (Bosco & Komi, 1979; Kibele, 1998; Linthorne, 2001; Ugrinowitsch et al., 2007). Impulse is represented by the area under the force time curves. However, the area under the vertical jump force-time curve contains an impulse used to support body weight, an impulse used to descend (the countermovement-unweighting phase) and slow down for the preparation of the propulsion (the countermovement-stretching phase for the countermovement jump only), and an

impulse that occurs during the slow-down of the center of mass due to the effect of the gravitational force as the body leaves the force plate (Kibele, 1998; Linthorne, 2001; Ugrinowitsch et al., 2007). Thus, an actual impulse that equates to the resultant jump height is only the portion of the total impulse indicated as the dark shaded area 3 for the countermovement jump and 1 for the static jump. This portion of the total impulse can be defined as a net impulse. As aforementioned, using the laws of constant acceleration and with a known system mass (body mass + external mass), a net impulse then can be used to predict a jump height. Thus, a measurement of a net impulse is theoretically equivalent to a measurement of a jump height.

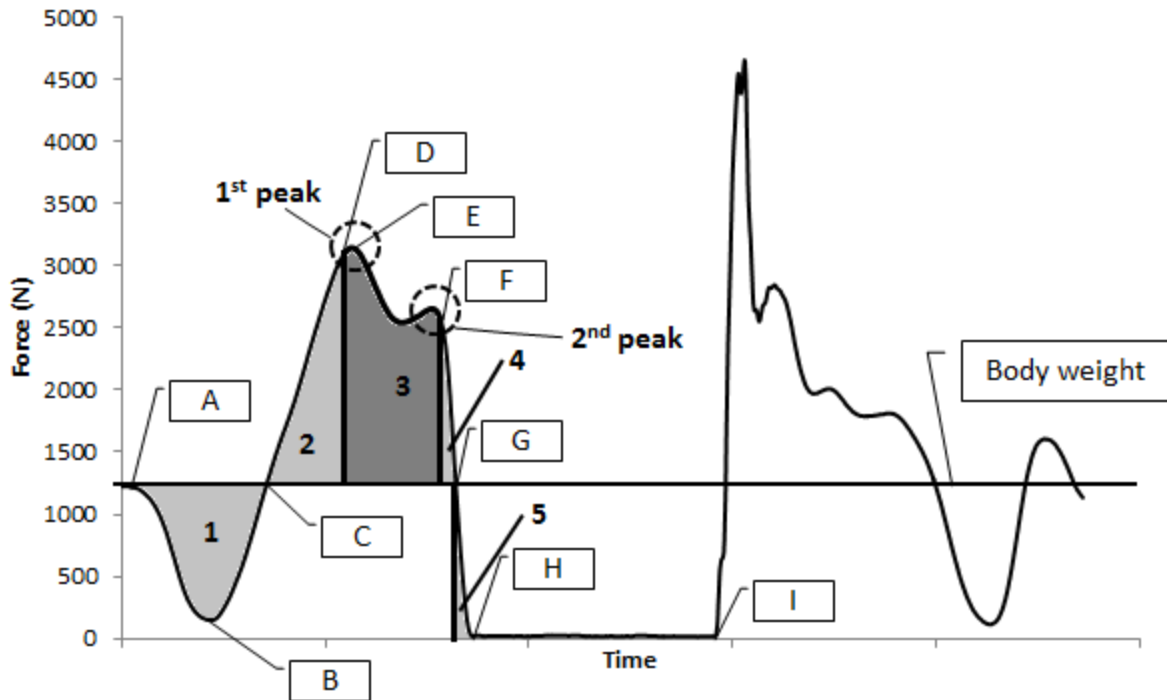
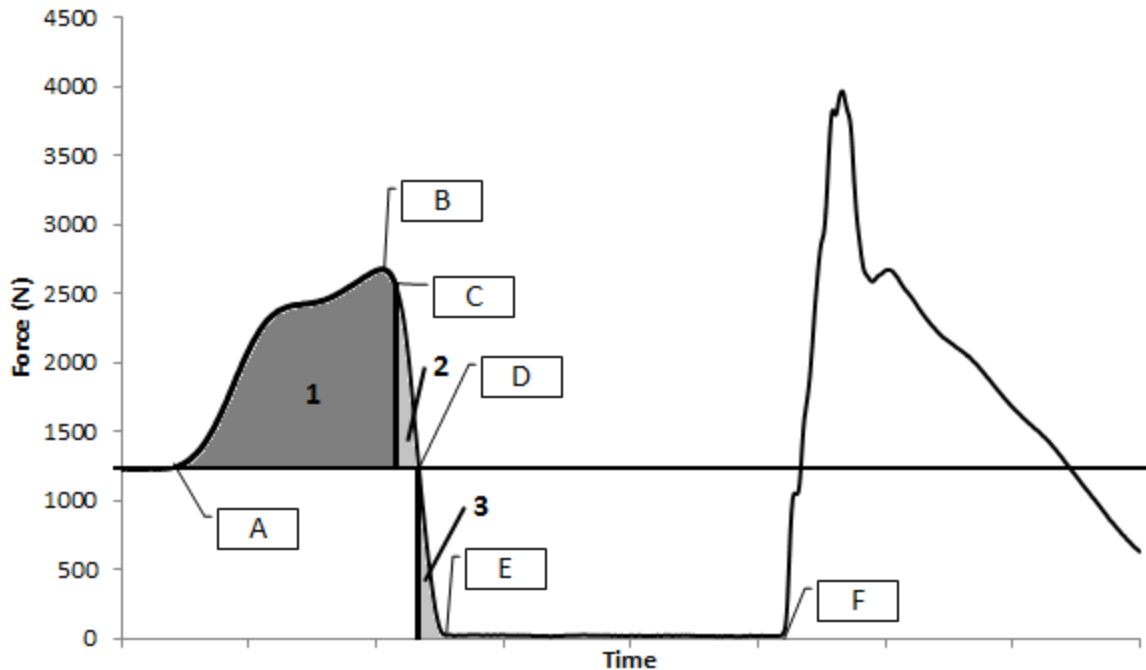


Figure 2.1 – Force-time curve of a counter-movement jump. A: The initiation of the countermovement. B: Peak negative force. C: Force returns to body weight and peak negative velocity is reached. D: The initiation of the propulsion phase, velocity becomes zero, and the beginning of a net impulse. E: Peak positive force. F: The vertical height of the center of mass almost reaches the initial height and this is the end of a net impulse. G: Force returns to body weight and peak positive velocity is reached. H: Take-off. I: Landing. The time between H and I is the flight phase and a jump height is defined as the vertical positive displacement of the center of mass from H to half-way through the flight phase. Shaded area 1: the countermovement-unweighting phase, which produces a negative impulse. Shaded area 2: the countermovement-stretching phase, in which the activation of the stretch shortening cycle function is expected. A positive impulse produced during this phase is equal to the absolute value of the negative impulse from the un-weighting phase. Shaded area 3: An area corresponding to net impulse. Shaded area 4: An area corresponding to the area of the shaded area 5 (the propulsion-

deceleration phase), a positive impulse, which is equal to the absolute value of the negative impulse from the shaded area 5. Combined area of 3 and 4: the propulsion-acceleration phase. Shaded area 5: the propulsion-deceleration phase, a negative impulse due to the gravity slowing down the body's upward movement. (Kibele, 1998; Linthorne, 2001; Ugrinowitsch et al., 2007)



*Figure 2.2* – Force-time curve of a static jump. A: The initiation of the propulsion from a squat position and the beginning of a net impulse. B: Peak positive force. C: The end of a net impulse. D: Force returns to body weight and peak positive velocity is reached. E: Take-off. F: Landing. The time between E and F is the flight phase and a jump height is defined as the vertical positive displacement of the center of mass from E to half-way through the flight phase. Shaded area 1: An area corresponding to net impulse. Shaded area 2: An area corresponding to the area of the shaded area 3 (the propulsion-deceleration phase), a positive impulse which is equal to the absolute value of the negative impulse from the shaded area 3. Combined area of 1 and 2: the propulsion-acceleration phase. Shaded area 3: the propulsion-deceleration phase, a negative impulse due to the gravity slowing down the body's upward movement. (Bosco & Komi, 1979; Kibele, 1998; Linthorne, 2001)



### Variables Related to Net Impulse

As aforementioned, a net impulse is a portion of a total impulse from the initiation of a whole jumping movement to take-off. By identifying this portion as a net impulse, it is then possible to characterize a net impulse of a given vertical jump. A number of kinetic and temporal variables that may be directly or indirectly related to a net impulse (or jump height) have been studied from force-time curves in previous studies (Dowling & Vamos, 1993; Garhammer & Gregor, 1992; Hansen, Cronin, & Newton, 2010; Moir et al., 2009; Sands et al., 1999; Ugrinowitsch et al., 2007). Although it is not realistic to discuss all variables as there are so many, some are more related to this dissertation than others and need to be discussed.

Dowling et al. (1993) examined relationships between countermovement jump height and a number of kinetic and kinematic variables. Of those, variables relevant to this dissertation are maximum force, shape factor, and ratio of negative impulse to positive impulse. Maximum force in their study was the highest force recorded during the propulsion phase of the countermovement jump. In a force-time curve normalized to body weight (i.e. body weight is subtracted), this indicates net impulse height. Shape factor was defined as a ratio of a positive impulse (shaded areas 2+3+4 or the entire positive impulse in Figure 2.1) to the area of a rectangle formed around the positive impulse. Shape factor was used to examine whether a positive impulse would approach a rectangular shape in more proficient jumpers. In this dissertation, the concept of shape factor can be useful in examining the shape of a net impulse. The ratio of negative impulse to positive impulse was namely the ratio between the two. In their study (Dowling & Vamos, 1993), a negative impulse was the area of the countermovement-unweighting phase (the shaded area 1) and a positive impulse was the same as for shape factor. This was based on the notion that too great or small a mechanical work during the

countermovement-unweighting phase could result in a sub-optimum jump height (e.g. too high or low a drop height results in sub-optimum depth jump height). Because the area of the countermovement-unweighting phase (the shaded area 1) is equal the area of the countermovement-stretching phase (the shaded area 2), this ratio can be considered as the proportion of the impulse of the countermovement-stretching phase to the entire positive impulse. This concept can be applied to this dissertation to examine the proportion of a net impulse to the entire positive impulse (the areas 2+3+4 and 1+2 for the countermovement and static jumps, respectively). With respect to the results of their study, moderate but statistically significant correlations were found between countermovement jump height and maximum force and the ratio of negative impulse to positive impulse. On the other hand, no statistically significant correlation was found between countermovement jump height and shape factor. However, because the positive impulse they measured included more than net impulse (the entire positive impulse: the shaded areas 2+3+4), the calculation of shape factor using net impulse may yield a different result.

Sands et al. (1999) examined temporal and kinetic characteristics of force-time curves from three different types of jumps in international level divers. One of the variables they reported was the slope from a force exceeding body weight to peak force. This variable corresponds to the slope from the point C to the point E in Figure 2.1. Although they did not directly examine how specifically the slope from a force exceeding body weight to peak force was related to jump performance, this variable could be important in characterizing a net impulse by modifying to a slope from point C to the point D (Figure 2.1). This is because it can be theorized that a net impulse can increase in magnitude as the slope approaches a vertical line with everything else held constant. Furthermore, as the area of the countermovement-stretching

phase ( the shaded area 2 in Figure 2.1) is considered to be the phase, in which the utilization of the stretch-shortening cycle takes place (Kibele, 1998), a greater slope could indicate a quicker stretch of muscle-tendon units for the better use of the stretch-shortening cycle.

Ugrinowitsch et al. (2007) compared a number of temporal, kinetic and kinematic variables from force-time curves of the countermovement jump between subjects with different training backgrounds (power-trained athletes, strength-trained athletes, and physically active non-athletes). One of the variables they measured was the concentric phase duration. This variable corresponds to the time duration from the point D to H in Figure 2.1. They reported that although there were no statistically significant differences found between the three groups, the power-trained athletes showed a trend towards a longer concentric phase duration than the other two groups. This was accompanied by a statistically significantly greater net impulse and jump height in the power-trained athletes than the other two groups. Their finding thus indicates that a part of the process to increase a net impulse through power training may be to increase the concentric phase duration. However, based on Newton's second law, an increase in net impulse results in a greater velocity, which consequently decreases the time to exert force to the ground. Thus, a greater concentric phase time probably indicates that the power-trained athletes had a greater magnitude of the countermovement than the other two groups. Nonetheless, if a change in the magnitude of the countermovement is also regarded as part of training adaptations, then temporal characteristics related to a net impulse may also help elucidate training adaptations. Therefore, in this dissertation, the time duration of a net impulse (width) from the point D to F is of interest.

Lastly, Cormie and colleagues (2008, 2009, 2010a, 2010d) have used a computer analytical technique, by which force-time curves from individual jumps are averaged into a single

force-time curve. Using this technique, individual force-time curves were re-sampled so that the number of data points was made equal. After this process, each data point could be statistically analyzed for difference. Although this technique is not of particular interest in this dissertation, it can become useful in showing graphical changes in net impulse in the future.

### Training-Induced Changes in Force-Time Curve

Although vertical jumping is a common mode of assessment in training studies, few studies have examined changes in force-time curves with peak force during the propulsion phase probably being the most common variable. However, Cormie and colleagues (2008, 2009, 2010a, 2010c, 2010d) have used the computer analytical technique as discussed in the previous section to examine training-induced changes in force-time curves graphically as well as in some measures of force-time curves. In this section, the results of their studies are discussed.

In one study, they compared ballistic power training and strength training of the lower extremity (Cormie et al., 2010a). In this study, ballistic power training was defined as training utilizing the countermovement jump with loads ranging from 0 to 30% back squat 1RM. Strength training was defined as conventional resistance training using back squat with loads ranging from 75 to 90% back squat 1RM. The training outcome assessment of performance consisted of sprint and the countermovement jump with 0% back squat 1RM in addition to other measurements. After 10 weeks of training, both groups improved jump height. However, there were differences found between the groups. 1) At the mid-point testing (5 weeks), the power training group showed an improvement in rate of force development measured from the point B to E in Figure 2.1 while the strength training group did not although there was a trend towards an increase. On the other hand, the power training group did not improve jump height (there was a trend towards an increase) while the strength training group improved jump height. 2) At the

post-training testing, the power training group showed an improvement in sprint performance at 20m, 30m, 40m, and flying 15m, while the strength training group showed an improvement only at 40m. 3) From visual comparison of the presented average force-time curves between the groups, it seems that the impulse measured as the area of the countermovement-unweighting phase (the shaded area 1 in Figure 2.1) showed an increase in the power training group while only the portion from point B to C in Figure 2.1 showed an increase in the strength training group. This in turn appeared to result in a greater increase in the area of the countermovement-stretching phase (the shaded area 2 in Figure 2.1) in the power training group. 4) The time from the initiation of the countermovement to take-off decreased in the power training group while it did not in the strength training group although there was a trend towards a decrease. 5) The magnitude of the first peak was seemingly greater than that of the second peak in the power training group while they were similar in the strength training group. These findings can be interpreted as follows. A) Power training leads to an increase in the velocity of the countermovement perhaps in an attempt to take greater advantage of the stretch-shortening cycle. This finding was supported by a subsequent study (Cormie et al., 2010c). B) Power training causes the whole countermovement jump movement to be performed more quickly, while greater force is still produced. This then may be related to an increase in the ability to reach top sprint speed more quickly than the strength training group. Based on these interpretations of the results, examination of variables related to the area of the countermovement-stretching phase (the shaded area 2 in Figure 2.1) (e.g. the slope from the point C to D, the proportion of the impulse of the countermovement-stretching phase to the entire positive impulse, and the difference between the magnitudes of the two peaks) may provide information on the aspect of acceleration and the stretch-shortening cycle function.

In another study, Cormie and colleagues (2010d) examined the effect of the initial strength level on adaptations to power training. Both stronger and weaker groups underwent the same power training program for 10 weeks. The power training in this study was the same as in the previous study. Both groups were assessed again in the countermovement jump with 0% back squat 1RM and a sprint test. Similar to the previous results, after 10 weeks of training, both groups improved jump height in the countermovement jump. However, there were differences found between the groups. 1) At the mid-point testing, the stronger group showed an increase in peak force while the weaker group did not, with both groups showing an increase in jump height. 2) At the mid-point testing, the stronger group already showed an improvement at all distances of the sprint test while the weaker group did not show an improvement at 5m, 10m, and flying 5m. 3) The average force-time curve of the stronger group did not appear to have the two peaks and to be more peaked than that of the weaker group with no changes in the ankle, knee, and hip joint angles during the countermovement jump. These findings can be interpreted as follows. A) The initial strength level positively influences net impulse height even from early on in training. This in turn seems to allow for greater acceleration early in sprinting (first 10 meters) and a quicker manifestation of the jump training adaptation in other movements such as sprinting. B) Along with the previous results, strength training (or having the background of strength training) may allow for the magnitude of the second peak to increase, which could contribute to the observation of the lack of the two peaks in the force-time curve of the stronger group. Based on these interpretations, examination of net impulse height and change in the magnitude of the second peak may provide information on the aspect of strength.

## Conclusion

In sport science, vertical jumping is commonly used to assess the explosiveness of the lower extremity. By using vertical jumping as a method of assessment, it seems that one can infer performance of other explosive movements, resistance training effectiveness, performance readiness for movements that require greater strength level (e.g. change of direction), and the function of the stretch-shortening cycle. With respect to net impulse and a force-time curve, a net impulse can be used to predict a jump height when a body mass is known. Furthermore, a net impulse can be indicated as the shaded area 3 or 1 in the countermovement or static jumps, respectively. The literature of sport science suggests that examinations of the portion corresponding to a net impulse as well as other portions and key measures of force-time curves have potential to relate observed characteristics of a force-time curve and net impulse to training adaptations and other explosive movement performance such as sprinting. Based on the review of the literature, the following seem to be variables of importance in this dissertation: size, height, width, and shape factor of net impulse, slope from the point C to D and the point A to B in countermovement and static jumps, respectively, and a proportion of net impulse (the shaded areas 3) to the entire positive impulse for the countermovement and static jumps. Lastly, training-induced changes in force-time curves are different depending on types of training (i.e. power vs. strength training) and the initial strength level of individuals. Power training seems to affect the countermovement-unweighting and stretching phases (the shaded areas 1 and 2) of the countermovement jump and causes the magnitude of the first peak to be much greater than that of the second peak than strength training (strength training still does result in the similar changes). Changes in force-time curves of individuals who have a greater level of initial strength appear to show the effects of both power and strength training.

## CHAPTER 3

Title: A New Approach to Determining Net Impulse and Its Characteristics in Vertical Jumping:

Test-Retest Reliability and Criterion Validity

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## **Abstract**

The purpose of the study was to investigate 1) test-retest reliability of alternative net impulse and net impulse characteristics (net impulse height and width, rate of force development, shape factor, and net impulse proportion) and 2) criterion validity of the alternative net impulse against criterion net impulse in the countermovement (CMJ) and static jumps (SJ). Twelve and 13 participants performed the CMJ and SJ, respectively, in two sessions (48 hours apart) with the same protocol for test-retest reliability. Twenty participants performed the two jumps with the same protocol for assessment of criterion validity. Test-retest statistics indicated consistent results for all the variables except for CMJ and SJ rates of force development and for SJ shape factor and net impulse proportion. In conclusion, 1) rate of force development particularly for the CMJ requires a large magnitude of change to overcome the variable's inherent variability. 2) Shape factor and net impulse proportion for the SJ should be used with caution and requires further investigations. 3) Alternative net impulse can be used interchangeably to criterion net impulse. Measurements of these variables may allow for sport scientists to study one's vertical jump performance in more depth.

## Introduction

Net impulse in vertical jumping can be defined as resultant impulse after the effect of gravity on system mass (e.g. body mass + external mass) is removed that gives *take-off* velocity when divided by system mass based on the impulse-momentum relationship (Enoka, 2008; Feltner, Bishop, & Perez, 2004; Hall, 2007; Hanson, Leigh, & Mynark, 2007; Linthorne, 2001; Moir, 2008; Street, McMillan, Board, Rasmussen, & Heneghan, 2001). In a simple mathematical sense, removal of the effect of gravity on system mass can be understood as the difference between the area under a force-time curve that is above system weight and the area(s) below system weight (Figures 2.1 and 2.2). Net impulse in vertical jumping has been calculated as a variable by itself or to estimate take-off velocity and/or jump height (Feltner et al., 2004; Hanson et al., 2007; Linthorne, 2001; Moir, 2008; Street et al., 2001). Traditionally, calculation of net impulse has relied on the integration of a force-time curve from a point prior to the initiation of a vertical jump to the point of take-off after system weight is subtracted (normalization) (Feltner et al., 2004; Hanson et al., 2007; Linthorne, 2001; Moir, 2008; Street et al., 2001).

The traditional approach to calculate net impulse has a theoretical background in that an impulse calculation considers the entire course of a movement (Enoka, 2008; Hall, 2007). However, this approach makes it impossible to identify what portion of a force-time curve of vertical jumping represents net impulse because an entire force-time curve is integrated. An alternative approach is to graphically isolate a portion representing net impulse (Figures 3.1 and 3.2). The isolation can be performed when one realizes the following. 1) During the countermovement jump (CMJ), the area of the countermovement-unweighting phase (see Figures 3.1 and 3.2 for phases) is equal to that of the countermovement-stretching phase (Kibele, 1998) and thus the integration can be started at the beginning of the propulsion phase. 2) During

the CMJ and static jump (SJ), an area equal to the area of the propulsion-*deceleration* phase needs to be subtracted from the area of the propulsion-*acceleration* phase because the slowing-down of the center of mass of the system during the propulsion-deceleration phase must be taken into consideration (Linthorne, 2001). The isolation of the portion representing net impulse is an important first step in defining variables that characterize net impulse.

Once the portion representing net impulse is isolated, net impulse can be characterized. Although net impulse can be characterized in many ways, this study focuses on characteristics that are considered to have a direct influence on net impulse. That is, changes in those characteristics are thought to result in a change in the isolated portion representing net impulse. Of these, kinetic and temporal characteristics are net impulse height and width of the isolated net impulse portion, rate of force development during the countermovement-stretching phase for the CMJ and from the beginning to peak force of the propulsion-acceleration phase for the SJ. In addition, characteristics of shape and proportion are shape factor or an index of how close the shape of the isolated net impulse portion is to a rectangular shape (Dowling & Vamos, 1993), and net impulse proportion or the proportion of the entire positive impulse (impulse that is positive in relation to system weight during the countermovement-stretching (the CMJ only) and propulsion-acceleration phases) occupied by net impulse (Figures 3.3 and 3.4).

To our knowledge, few studies calculated net impulse using the proposed alternative approach and the above-discussed variables to characterize net impulse. Because of this, little is known regarding validity and reliability of these variables. Therefore, the purposes of this study were to investigate 1) test-retest reliability of net impulse calculated with the alternative approach and the net impulse characteristics and 2) criterion validity of net impulse calculated with the alternative approach in comparison to the traditional approach in both the CMJ and SJ.

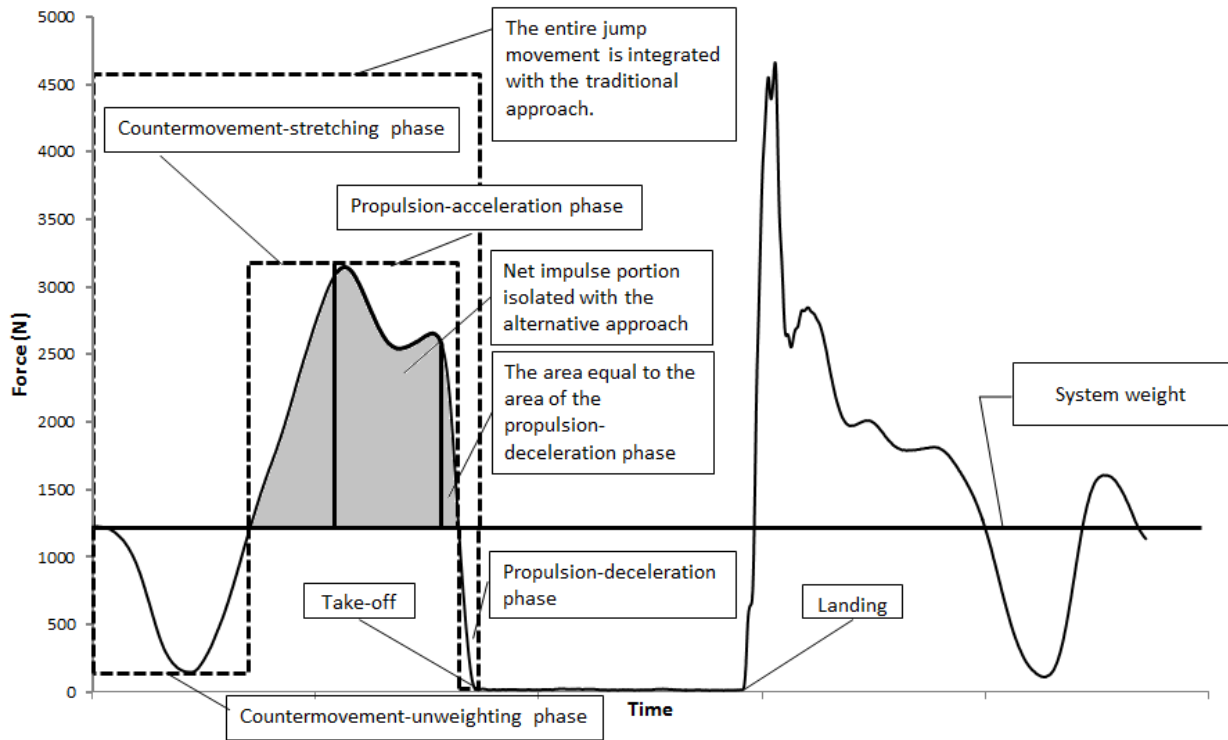


Figure 3.1 – Phases during the countermovement jump. The grey shaded area indicates the entire positive impulse in relation to system weight.

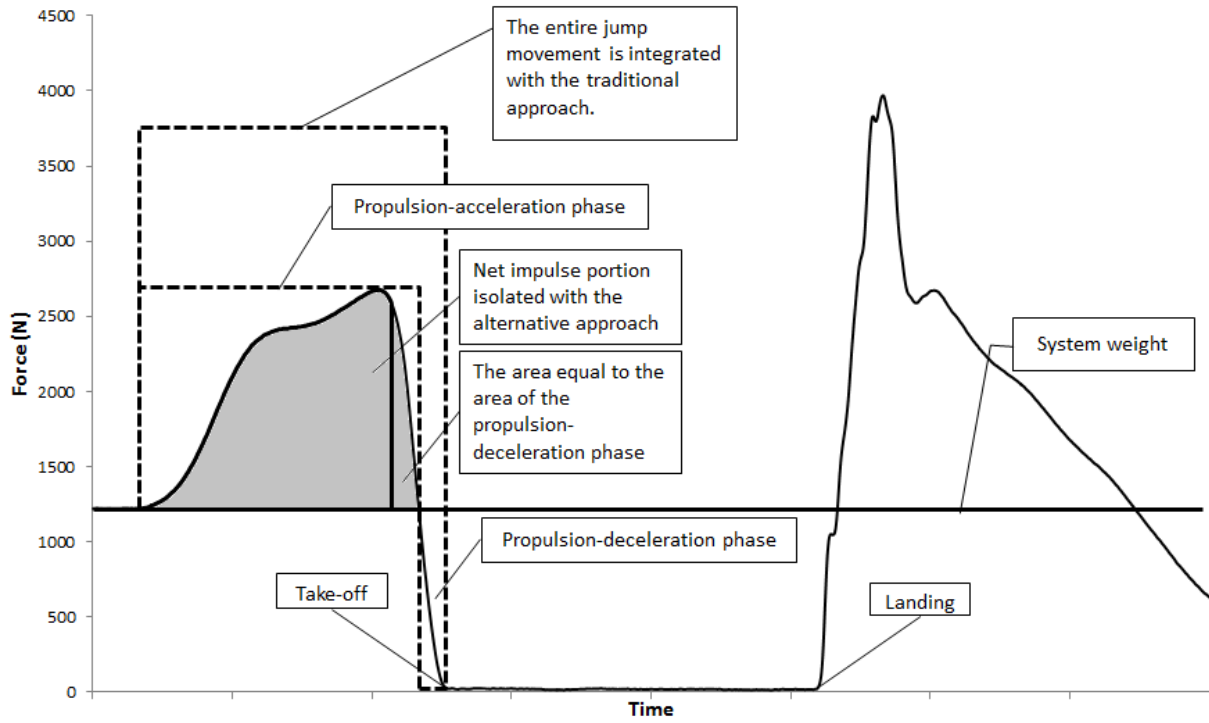


Figure 3.2 – Phases during the static jump. The grey shaded area indicates the entire positive impulse in relation to system weight.

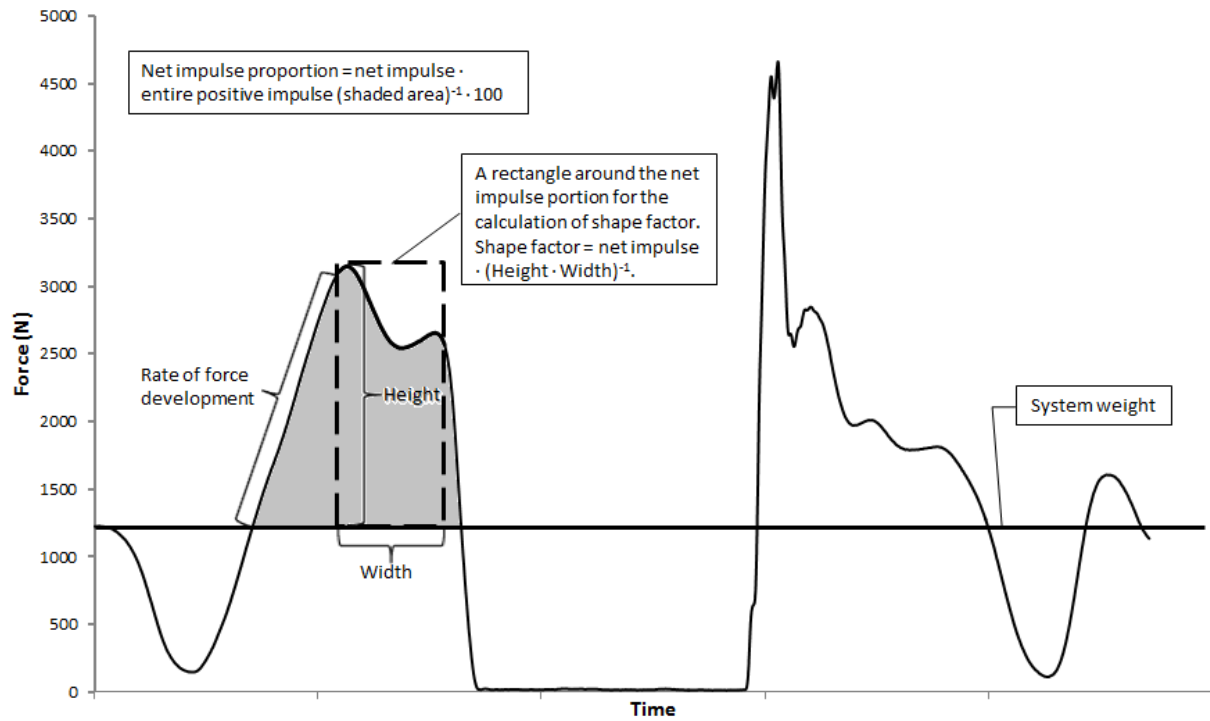


Figure 3.3 – Net impulse characteristics of the countermovement jump. The grey shaded area indicates the entire positive impulse in relation to system weight.

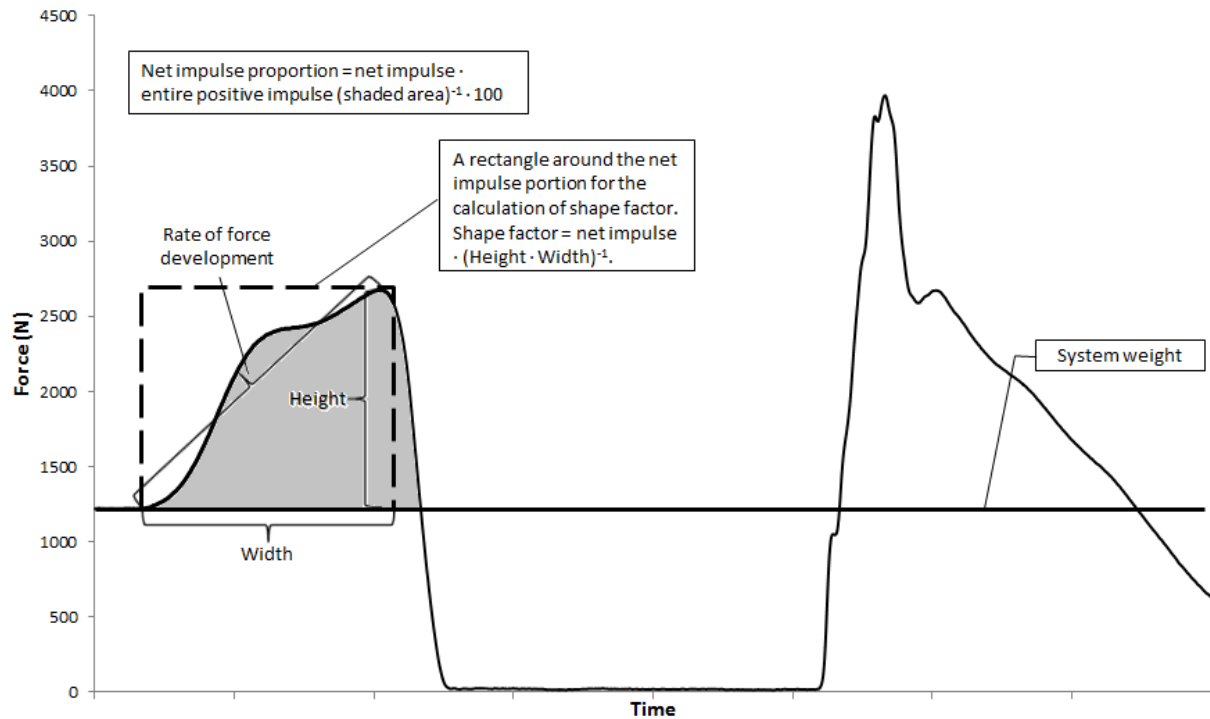


Figure 3.4 – Net impulse characteristics of the static jump. The grey shaded area indicates the entire positive impulse in relation to system weight.

## Methods

### *Experimental Approach*

In order to investigate test-retest reliability and criterion validity, the study was conducted in two parts using two different samples of participants. In Part 1, test-retest reliability was examined for net impulse by the alternative approach and the net impulse characteristics. To examine test-retest reliability, participants were tested for the CMJ and SJ in two sessions separated by 48 hours. To ensure the participants' same physical conditions, they were asked to not exercise 24 hours prior to both sessions and were tested at the same time of a day. In Part 2, criterion validity of net impulse by the alternative approach was examined. To examine the criterion validity, participants were tested for the CMJ and SJ. The obtained net impulse by the

alternative approach was then compared to net impulse by a criterion approach (the traditional approach).

### *Participants*

In Part 1, 14 participants were recruited. These participants consisted of exercise science undergraduate students who were physically active. Of these, four participants were competitive athletes (Sports: Track and field throwing event, Gymnastics, Soccer, and Cycling). After the data collection, the 14 participants were screened for consistency in the CMJ and SJ performance based on jump height. This was performed by searching for outliers in the jump height difference between the two sessions. Outliers were defined as values that fell outside 1.5 times the jump height difference range between the 25<sup>th</sup> and 75<sup>th</sup> percentile of the sample (Kinnear & Gray, 2010). As a result, two outliers were identified and the sample size was reduced to N = 12 for the CMJ (6 males and 6 females, age:  $22.0 \pm 3.0$  y, height:  $1.76 \pm 0.11$  m, and body mass:  $76.9 \pm 26.9$  kg). One outlier was identified and the sample size was reduced to N = 13 for the SJ (7 males and 6 females, age:  $22.2 \pm 2.8$  y, height:  $1.75 \pm 0.12$  m, and body mass:  $76.9 \pm 26.9$  kg). In Part 2, 20 different participants (N = 20) from Part 1 were recruited (15 males and 5 females, age:  $23.0 \pm 5.3$  y, height:  $1.80 \pm 0.11$  m, and body mass:  $95.7 \pm 20.8$  kg). All participants in Part 2 were also physically active. Of the 20 participants, 3 were baseball players, 2 were volleyball players, 5 were track and field throwers, and 5 were weightlifters. All these athletes competed at the American National Collegiate Athletic Association (NCAA) Division I level except for the 5 weightlifters who were also competitive but not included in the NCAA sports. All participants read and signed informed consent documents prior to participating in this study. This study was approved by the Institutional Review Board of East Tennessee State University.



### *Jump Testing*

For Part 1 (Test-retest reliability), there were one familiarization and two testing sessions. The familiarization session was held 72 hours prior to the first testing session. The two testing sessions were identical in the procedures and were separated by 48 hours. All participants were asked to refrain from any vigorous physical activities 48 hours prior to a testing session and from any exercise 24 hours prior to a testing session. The jump testing session began with warm-up by performing 20 jumping-jacks, 3 submaximal CMJs and 2 maximal CMJs from their preferred depth. Following the warm-up, the participants performed at least 2 trials of maximal CMJs. After the CMJ trials, they performed 2 submaximal SJs and then at least 2 trials of maximal SJs from a 90-degree knee angle. All participants were instructed to perform jumps with maximum effort while holding a nearly weightless PVC pipe across the back of the shoulders. The PVC pipe was held to prevent arm swings, which allowed for the measurement of the lower body performance only (Feltner et al., 2004; Harman, Rosenstein, Frykman, & Rosenstein, 1990; Lees, Vanrenterghem, & De Clercq, 2004). A rest period of 60 seconds was given between maximal jump trials. For the maximal trials, participants performed 2 or more trials until 2 consistent jump heights were recorded (criterion:  $\leq \pm 5\%$  difference in jump height). Jump heights were monitored with linear position transducers (Celesco, Chatsworth, CA, USA) attached to both ends of the PVC pipe. During the SJs, any noticeable countermovement disqualified the trial and another trial was performed.

The following variables were examined from the collected data in Part 1: jump height, criterion net impulse, alternative net impulse, net impulse height (peak force minus system weight), net impulse width (alternative net impulse duration), rate of force development, shape factor, and net impulse proportion. Multiple trials for all variables were used to reduce random

error inherent in any measurements and to assess trends across trials, differences between trials, and thus trial stability (Henry, 1967; Kroll, 1967).

The testing session for Part 2 (Criterion validity) consisted of one testing session. No familiarization session was held as all participants were already familiar with the testing protocols (Moir, Button, Glaister, & Stone, 2004). The participants began the testing session with a previously described standardized-protocol (Kraska et al., 2009). The participants then performed two sub-maximal CMJs and SJs as a specific warm-up. All participants were instructed to perform jumps with maximum effort while holding the same PVC pipe across the back of the shoulders. The actual testing session was identical in the protocol as in Part 1. Multiple trials for all variables were also used.

#### *Variable Measurements and Calculations*

Jump height was estimated from flight time (i.e. time between take-off and landing) (Aragón-Vargas, 2000; Bosco, Tihanyi, Komi, Fekete, & Apor, 1982; Carlock et al., 2004). The test-retest reliability of jump height based on flight time has been reported to be sufficient previously (Moir, Garcia, & Dwyer, 2009). The measurements and calculations of net impulse and its related variables are illustrated in Figures 3.3 and 3.4. Briefly, criterion net impulse was calculated after normalization (subtraction of system weight from a force-time curve) by integration of a force-time curve from a point prior to the initiation of a vertical jump to the point of take-off (Feltner et al., 2004; Hanson et al., 2007; Linthorne, 2001; Moir, 2008; Street et al., 2001). Alternative net impulse was calculated as the area under a force-time curve described in Figures 3.3 and 3.4. Net impulse height was measured as a difference between a participant's system weight and the peak force measured during the propulsion-acceleration phase. Net impulse width was measured as a time duration over which the area representing alternative net

impulse spanned. Rate of force development was calculated by dividing a difference in force between 2 points by a time duration between the 2 points. The 2 points were the beginning and the end of the countermovement-stretching phase for the CMJ and the beginning and the peak force of the propulsion-acceleration phase for the SJ. Shape factor was calculated as a ratio of alternative net impulse to the area of the smallest rectangle that was formed around the alternative net impulse portion. Net impulse proportion was calculated as a proportion of alternative net impulse to the entire positive impulse in percentage.

#### *Testing Devices and Analysis Program*

All jumps were performed on a force plate (0.91 m x 0.91 m, Rice Lake Weighing Systems, Rice Lake, WI, USA). Vertical ground reaction force was sampled at 1000Hz. Data analyses were performed using a program designed with LabVIEW (ver. 2010, National Instruments, Austin, TX, USA). A digital low-pass Butterworth filter with a cutoff frequency of 10 Hz was used to remove noise.

#### *Statistical Analyses*

Values from two consistent trials were averaged for further statistical analyses for all variables to reduce random error (Henry, 1967). In Part 1, relative or rank-order relationship test-retest reliability (Atkinson & Nevill, 1998) was assessed based on intra-class correlation coefficient with the two-way mixed model for consistency (ICC) while absolute or between-session difference test-retest reliability (Atkinson & Nevill, 1998) was assessed based on a coefficient of variation (CV) (Hopkins, 2000) and 95% limits of agreement (95% LOA) (Atkinson & Nevill, 1998). Heteroscedasticity was assessed using a Pearson product moment correlation coefficient, and statistical differences between the sessions using a paired-sample t-test. In Part 2, criterion validity was assessed using a Pearson product moment correlation

coefficient, 95% limits of agreement, Bland-Altman's plot (Atkinson & Nevill, 1998), and a paired-sample t-test. All statistical analyses except for a CV, 95% LOA, and a Bland-Altman's plot were performed using The Predictive Analytics Software version 19 (SPSS: An IBM company, New York, NY). The calculations or constructions of CV, 95% LOA, and Bland-Altman's plot were performed using Microsoft Office Excel 2010 (Microsoft Cooperation, Redmond WA). In Part 1, the critical alpha level was adjusted from  $p \leq 0.05$  for paired-sample t-tests using simple sequentially rejective test (Holm, 1979) to control for an increase in the type I error rate. For an ICC and CV, associated 90% confidence intervals (90% CI) were calculated as suggested by Hopkins et al. (Batterham & Hopkins, 2006; Hopkins, 2000).

## **Results**

### *Part 1 – Test-retest Reliability*

Results of the reliability analysis indicated that most of the variables were consistent between the two sessions (Tables 3.1-3.4). Results of paired-sample t-tests showed that there were no statistical differences between the two sessions in any of the variables of the CMJ while a statistical difference was found in net impulse proportion of the SJ (Figure 3.5). Heteroscedasticity was identified in net impulse height of the CMJ and rate of force development of the SJ. Calculations of the other reliability statistics showed that rate of force development of the CMJ had the lowest consistency in terms of ICC, 95% LOA, 95% LOA in ratio, and CV. For the SJ, shape factor showed the lowest consistency in terms of ICC with 95% LOA, 95% LOA in ratio, and CV being comparable to the other variables and rate of force development showed the lowest consistency in terms of 95% LOA, 95% LOA in ratio, and CV. However, for shape factor of the SJ, one outlier was found for the variable's between-session difference even after the data were screened for outliers in the jump height difference (Figure 3.6). Removal of the outlier from

the data improved the ICC value for shape factor of the SJ to 0.93 (95% CI: 0.76 – 0.98), 95% LOA to  $0.00 \pm 0.04$ , 95% LOA in ratio to  $1.00 \times/\div 1.08$ , and CV to 2.6% (mean  $\pm$  standard deviation: Session1 =  $0.58 \pm 0.04$  and Session 2 =  $0.57 \pm 0.05$ ). The result with the outlier is presented in Table 3.2 as per the criterion of the initial screening for the jump height difference. There was not an apparent change for the participant that produced the outlier in shape factor of the SJ in the criterion net impulse values (227.2 N·s vs. 225.9 N·s) but the changes in net impulse height and width were more apparent (1211.8 N vs. 1156.7 N and 296.5 ms vs. 389.5 ms, respectively).

### *Part 2 – Criterion Validity*

Comparison of alternative net impulse to criterion net impulse showed that the two were comparable for both the CMJ and SJ (Tables 3.5 and 3.6). Although heteroscedasticity was identified along with systematic bias (paired sample t-test) for the CMJ, 95% LOA and 95% LOA in ratio showed that the identified heteroscedasticity has a minimal influence on the predicted difference between the two approaches (i.e. 0.18-2.18 N·s). Furthermore, using the regression equation in Figure 3.7, an extreme value of 1000 N·s for criterion net impulse would correspond to a value of 1004.20 N·s for alternative net impulse. That is, the difference will only be 4.20 N·s.

Table 3.1 – Countermovement jump results from the two sessions.

	CMJ (N = 12)		Paired t-test p value
	Mean ± SD		
	Session 1	Session 2	
Jump height (m)	0.27 ± 0.08	0.27 ± 0.07	0.08
Criterion net impulse (N·s)	176.2 ± 51.88	175.28 ± 53.03	0.27
Alternative net impulse (N·s)	177.03 ± 52.11	175.98 ± 53.24	0.24
Net impulse height (N)	820.28 ± 199.62	849.56 ± 240.66	0.17
Net impulse width (ms)	248.58 ± 26.11	244.79 ± 38.56	0.51
Rate of force development (N·s <sup>-1</sup> )	3673.32 ± 929.59	4021.5 ± 1572.18	0.30
Shape factor	0.86 ± 0.06	0.85 ± 0.07	0.36
Net impulse proportion (%)	63.22 ± 3.42	63.42 ± 3.44	0.61

### 3.2 – Test-retest statistics of the countermovement jump variables.

	CMJ (N = 12)				
	ICC (95% CI)	Heteroscedasticity (r)	95% LOA	95% LOA (ratio)	CV (90% CI)
Jump height (m)	1.00 (0.99-1.00)	0.02	0.00 ± 0.02	0.98 ×/÷ 1.07	2.3% (1.7-3.6%)
Criterion net impulse (N·s)	1.00 (1.00-1.00)	0.32	1.05 ± 5.78	1.01 ×/÷ 1.03	1.2% (0.9-1.9)
Alternative net impulse (N·s)	1.00 (1.00-1.00)	0.29	0.99 ± 5.83	1.01 ×/÷ 1.03	1.2% (0.9-1.9%)
Net impulse height (N)	0.98 (0.91-0.99)	0.78*	-29.28 ± 136.28	0.97 ×/÷ 1.13	4.6% (3.4-7.2%)
Net impulse width (ms)	0.91 (0.68-0.97)	0.38	3.79 ± 37.34	1.02 ×/÷ 1.15	5.1% (3.8-8.1%)
Rate of force development (N·s <sup>-1</sup> )	0.78 (0.24-0.94)	0.38	-348.17 ± 2150.85	0.96 ×/÷ 1.75	22.3% (16.2-36.6%)
Shape factor	0.89 (0.60-0.97)	0.11	0.01 ± 0.08	1.01 ×/÷ 1.10	3.3% (2.5-5.2%)
Net impulse proportion (%)	0.96 (0.87-0.99)	-0.06	-0.20 ± 2.54	1.00 ×/÷ 1.04	1.5% (1.1-2.3%)

ICC = intraclass correlation coefficient, r = Pearson r, 95% LOA = 95% limits of agreement, and CV = coefficient of variation.

\*Statistically significant correlation.

Table 3.3 – Static jump results from the two sessions.

	SJ (N = 13)		
	Mean $\pm$ SD		Paired t-test p value
	Session 1	Session 2	
Jump height (m)	0.24 $\pm$ 0.06	0.24 $\pm$ 0.07	0.36
Criterion net impulse (N·s)	170.93 $\pm$ 65.9	169.65 $\pm$ 69.05	0.29
Alternative net impulse (N·s)	171.13 $\pm$ 65.81	169.75 $\pm$ 69.15	0.25
Net impulse height (N)	844.09 $\pm$ 283.57	837.86 $\pm$ 283.75	0.60
Net impulse width (ms)	355.42 $\pm$ 39.53	349.31 $\pm$ 49.17	0.51
Rate of force development (N·s <sup>-1</sup> )	2551.36 $\pm$ 794.02	2624.67 $\pm$ 902.58	0.63
Shape factor	0.57 $\pm$ 0.04	0.58 $\pm$ 0.05	0.42
Net impulse proportion (%)	90.8 $\pm$ 2.05*	90.45 $\pm$ 2.14	0.03

\*Statistical difference between the sessions.



Table 3.4 – Test-retest statistics of the static jump variables.

	SJ (N = 13)				
	ICC (95% CI)	Heteroscedasticity (r)	95% LOA	95% LOA (ratio)	CV (90% CI)
Jump height (m)	0.99 (0.96-1.00)	0.42	0.00 ± 0.03	1.02 ×/÷ 1.11	4.0% (3.0-6.1%)
Criterion net impulse (N·s)	1.00 (1.00-1.00)	0.4	1.28 ± 8.08	1.01 ×/÷ 1.04	1.5% (1.2-2.3%)
Alternative net impulse (N·s)	1.00 (1.00-1.00)	0.39	1.38 ± 8.08	1.01 ×/÷ 1.05	1.5% (1.2-2.4%)
Net impulse height (N)	1.00 (0.98-1.00)	0.16	6.23 ± 81.24	1.01 ×/÷ 1.11	3.7% (2.8-5.6%)
Net impulse width (ms)	0.85 (0.50-0.95)	-0.4	6.12 ± 63.78	1.03 ×/÷ 1.22	7.2% (5.4-11.2%)
Rate of force development (N·s <sup>-1</sup> )	0.89 (0.63-0.97)	0.55*	-73.31 ± 1061.14	0.98 ×/÷ 1.44	13.5% (10.1-21.2%)
Shape factor	0.71 (0.05-0.91)	0.1	-0.01 ± 0.08	0.98 ×/÷ 1.16	5.4% (4.0-8.2%)
Net impulse proportion (%)	0.98 (0.95-1.00)	-0.15	0.35 ± 1.02	1.00 ×/÷ 1.01	0.4% (0.3-0.6%)

ICC = intraclass correlation coefficient, r = Pearson r, 95% LOA = 95% limits of agreement, and CV = coefficient of variation.

\*Statistically significant correlation.

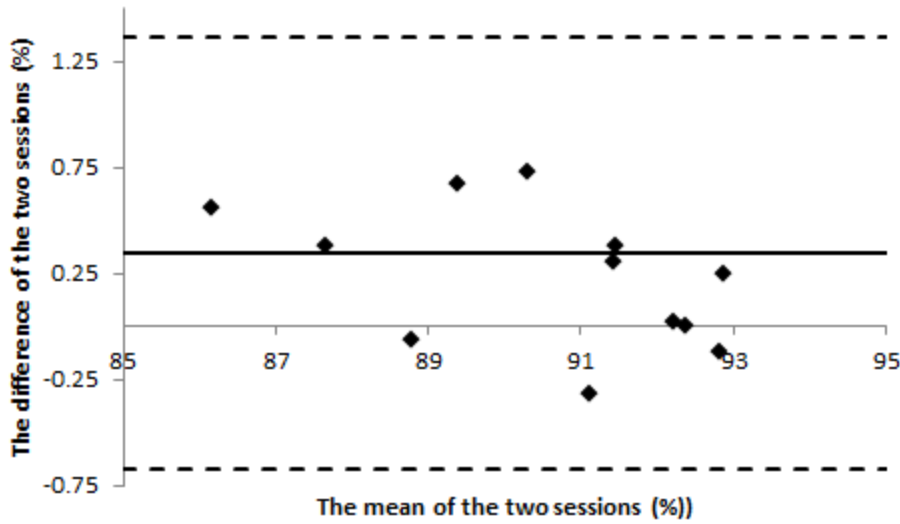


Figure 3.5 – Bland-Altman’s plot for net impulse proportion for the static jump. The solid line indicates the mean difference between the sessions. The broken lines indicate the 95% limits of agreement.

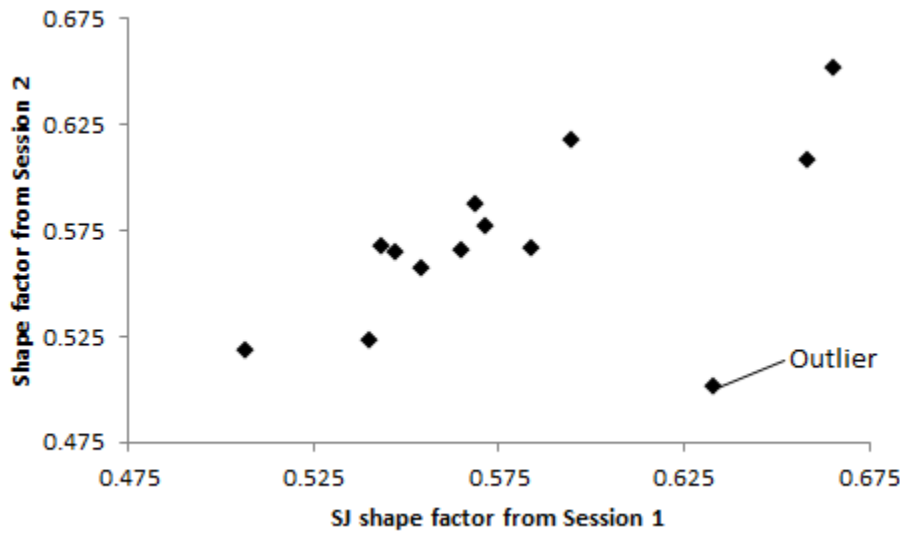


Figure 3.6 – Comparison of Sessions 1 and 2 for the static jump shape factor.

Table 3.5 – Comparison of the criterion to alternative approaches.

	Mean ± SD		Paired t-test p value
	Criterion (N·s)	Alternative (N·s)	
Countermovement jump	245.96 ± 63.83	247.14 ± 64.08*	<0.0001
Static jump	215.68 ± 58.83	215.64 ± 58.81	0.524

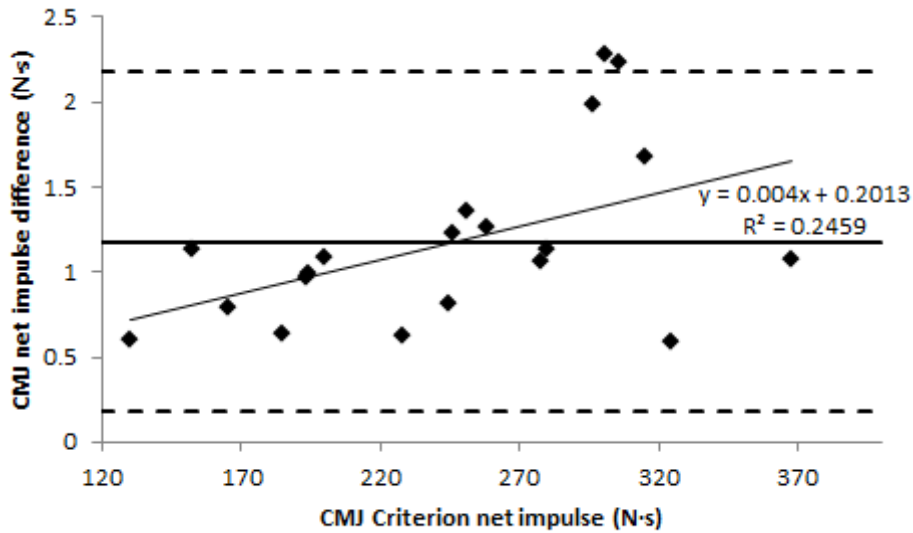
Criterion = the criterion net impulse and Alternative = the alternative net impulse. \*Statistical difference between the approaches.

Table 3.6 – Criterion validity statistics of the alternative approach to calculate net impulse.

	Correlation with jump height		Rank-order relationship (r)	Heteroscedasticity (r)	95% LOA (N·s)	95% LOA (ratio)
	Criterion	Alternative				
Countermovement jump	0.97*	0.97*	1.00*	0.50*	1.18 ± 1.00	1.00 ×/÷ 1.00
Static jump	0.98*	0.98*	1.00*	-0.07	-0.04 ± 0.55	1.00 ×/÷ 1.00

Criterion = the criterion net impulse, Alternative = the alternative net impulse, r = Pearson r, and 95% LOA = 95% limits of agreement.

\*Statistical significance.



*Figure 3.7* – Bland-Altman’s plot for examination of criterion validity of the alternative net impulse for the countermovement jump. The CMJ net impulse difference = the alternative net impulse - the criterion net impulse. The thick solid line indicates the mean difference between the sessions. The broken lines indicate the 95% limits of agreement. The best fit line (the thin solid line) is inserted along with the associated regression equation to show the observed heteroscedasticity.

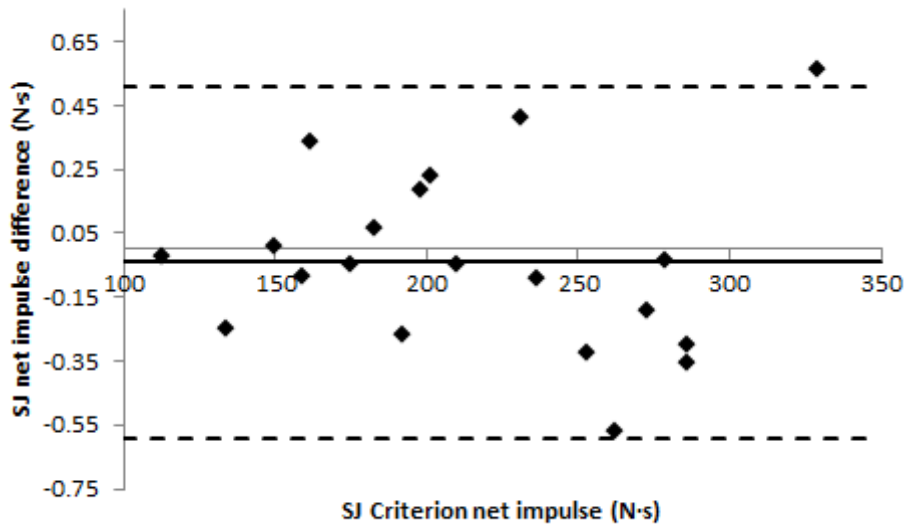


Figure 3.8 – Bland-Altman’s plot for examination of criterion validity of the alternative net impulse for the countermovement jump. The SJ net impulse difference = the alternative net impulse - the criterion net impulse. The thick solid line indicates the mean difference between the sessions. The broken lines indicate the 95% limits of agreement.

## Discussion

There were five primary findings in this study. 1) Rate of force development for the CMJ has the lowest test-retest reliability in terms of the rank-order relationship and the between-session difference. 2) For the SJ, rate of force development has the lowest consistency in terms of the between-session difference. 3) Shape factor potentially has the lowest consistency in terms of the rank-order relationship for the SJ. 4) Systematic bias in net impulse proportion of the SJ may be due to the artifact of the variable’s small variability. 5) The alternative net impulse is nearly identical to criterion net impulse for both the CMJ and SJ.

The lowest test-retest reliability for rate of force development for the CMJ suggests that a large magnitude is required for observed changes to be meaningful (Table 3.2). As evident in all the reliability measures, rate of force development for the CMJ has large variability between the

sessions. Although the rank-order relationship indicated by  $ICC = 0.78$  may not appear low, the associated 95% CI was found to be large and the between-session difference indicated by 95% LOA, 95% LOA in ratio, and CV was the greatest of the variables of the CMJ. A previous study reported similar ICC and CV values ranging from 0.69 to 0.90 and from 13.3 to 20.6% for rate of force development during the CMJ measured from the lowest to the highest forces (Moir et al., 2009). Rate of force development measured in their study spans over a greater time duration (across parts of the countermovement-unweighting and propulsion-acceleration phases) compared to that in this study (only during the countermovement-stretching phase). Moreover, ICC and CV for other methods of calculating rate of force development (shorter and longer time durations and thus in or across different phases compared to this study) report similar values as well, particularly for CV (Hori et al., 2009; McLellan, Lovell, & Gass, 2010; Moir et al., 2009). Thus, the observed variability in this study for rate of force development for the CMJ may be due to an inherent factor related to the dynamics of the CMJ itself. Although the between-session difference for rate of force development of the CMJ in this study appears large, the more consistent rank-order relationship can indicate that inter-individual comparisons for this variable can be made to a reasonable extent (e.g. those with high rate of force development would likely produce high rate of force development in another testing session if they were measured under the same condition). Thus, use of this variable is possible in cross-sectional studies examining the relationship of this variable with other variables or group differences with increased internal validity by increasing heterogeneity of the sample. Furthermore, this does not mean that rate of force development can not be used in intervention-based studies. The important consideration for studies examining intervention-related changes is that differences must be larger than the inherent variability of the variable.

Likewise, for the SJ, the greatest between-session difference in rate of force development suggests that this variable also requires a large magnitude for any measured changes to be attributed to an intervention effect (Table 3.3). Compared to the CMJ, rate of force development of the SJ showed the better rank-order relationship and between-session difference. In particular, the ICC = 0.89 appears more convincing that this variable can be used in cross-sectional studies. The smaller between-session difference compared to the CMJ may be attributed to reduced dynamics during the SJ (i.e. there is no countermovement phase in the SJ) and the standardization of the knee angle in the squat position prior to the propulsion phase. A previous study reported a similar ICC value of 0.84 but a much lower CV value of 6.5% using the identical protocol and method of calculation (Moir, Sanders, Button, & Glaister, 2005) compared to this study. The lower CV value in the previous study may be attributed to use of the average of three trials instead of two trials, further reducing random error (Henry, 1967).

In addition, for the SJ, the lowest consistency for the rank-order relationship for shape factor warns that this variable be used cautiously in both cross-sectional and intervention-based studies. However, the removal of one outlier resulted in the noticeable improvement of the ICC value. Although the effect of the outlier on the reliability statistics is apparent, this suggests that an individual can achieve the same jump height and net impulse through different kinetic and temporal combinations (i.e. net impulse height and width). This in turn indicates that shape factor may be a variable more sensitive to changes in one's jumping technique than jump height is. This implies the variable's potential role in some aspects of athletes' performance monitoring and sport science research such as fatigue monitoring and post-activation potentiation protocols, which could influence jumping technique. However, at the same time, the observed variability could be simply due to variation inherent in the human biological system and may not be related



to any external factors at all. Thus, more research examining test-retest reliability of this variable is needed and caution should be exercised when using shape factor for the SJ as a measure of vertical jump performance.

The systematic bias indicated by a paired-sample t-test for net impulse proportion of the SJ may be the artifact of the variable's small variability. Of all the variables measured for the SJ, net impulse proportion was the only one that showed systematic bias. The cause of the systematic bias is not clear. However, if there was inconsistency in the participants' conditions and/or in the data analysis process, it is more reasonable to see systematic bias in one or more other variables, if not all, as well, because all the variables were obtained from the same force-time curves. Closer examination of the results reveals the small variability of the variable (i.e. CV = 0.4% and Figure 3.6). Although speculative, it may be more reasonable to suggest that the systematic bias was due to an artifact of the small variability. That is, the likelihood of systematic bias may be increased because the variable varies within such a small range that changes in individual values could be coincidentally more in one direction. Further research is needed probably with a greater sample size to reach a more definitive conclusion.

Last, the nearly identical results between criterion and alternative net impulses suggest that the two can be used interchangeably (Tables 3.3 and 3.4). When jump height results are consistent, criterion and alternative net impulses are comparable to each other in terms of test-retest reliability and criterion validity. Furthermore, the two approaches revealed the apparent consistency in the test-retest reliability statistics (Table 3.3). A concern may be the heteroscedasticity found between the two approaches (Table 3.4). However, as explained in the result section, the effect of heteroscedasticity on the magnitude of difference between the two is estimated to be small even for an un-realistic extreme value. The results of test-retest reliability

and criterion validity suggest that alternative net impulse can be used in place of criterion net impulse for both cross-sectional and intervention-based studies.

In conclusion, the findings of the study indicate the following. 1) Most of the variables examined in this study can be used in both cross-sectional and intervention-based studies. 2) However, rate of force development particularly of the CMJ requires a large magnitude of change to overcome the variable's inherent variability. 3) Shape factor and net impulse proportion of the SJ should be used with caution and requires further investigations. 4) The alternative approach to calculate net impulse can be used in place of the criterion approach. The use of the alternative approach allows for the graphical expression of the area in a force-time curve representing net impulse. This in turn allows other variables characterizing net impulse such as those examined in this study to be clearly defined. Measurements of these variables may allow for sport scientists to study one's vertical jump performance in more depth.

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## CHAPTER 4

Contributions of net impulse characteristics to predicting vertical jump height

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Running title: Contributions to jump height.

Funding: This study was not funded.

## Abstract

**Purpose:** The purpose of this study was to investigate 1) a contribution of each net impulse characteristic to predicting jump height in collegiate athletes and 2) how net impulse characteristics differ according to levels of jump height. This study may reveal the degree of importance of a characteristic to achieve a high jump height. **Methods:** Records of 130 collegiate athletes were retrieved from our laboratory archive for this study. They performed the countermovement (CMJ) and static (SJ) jumps. Net impulse and its characteristics (net impulse height and width, rate of force development, shape factor, and net impulse proportion) were obtained from vertical jump force-time curves. **Results:** Multiple regression analyses showed that net impulse height (peak force minus system weight) and width and shape factor were found to contribute to the CMJ height whereas all net impulse characteristics were found to contribute to the SJ height (CMJ: adjusted  $R^2 = 0.83$  and SJ: adjusted  $R^2 = 0.90$ ). Furthermore, relative net impulse height (net impulse height divided by system mass) had the greatest contribution for both jumps. When participants were divided into five groups based on jump height, one-way analyses of variance showed statistical differences only for relative net impulse height for the CMJ. For the SJ, statistical differences were found for relative net impulse height, net impulse width, rate of force development, and net impulse proportion. **Conclusion:** The net impulse characteristics found to contribute can be useful in gaining mechanistic insight into changes in jump height and indirectly in net impulse. Relative net impulse height appears to be an important characteristic to achieve a high jump height for the CMJ and SJ and net impulse proportion for the SJ.

Key words: force-time curve, multiple regression analysis, countermovement jump, static jump



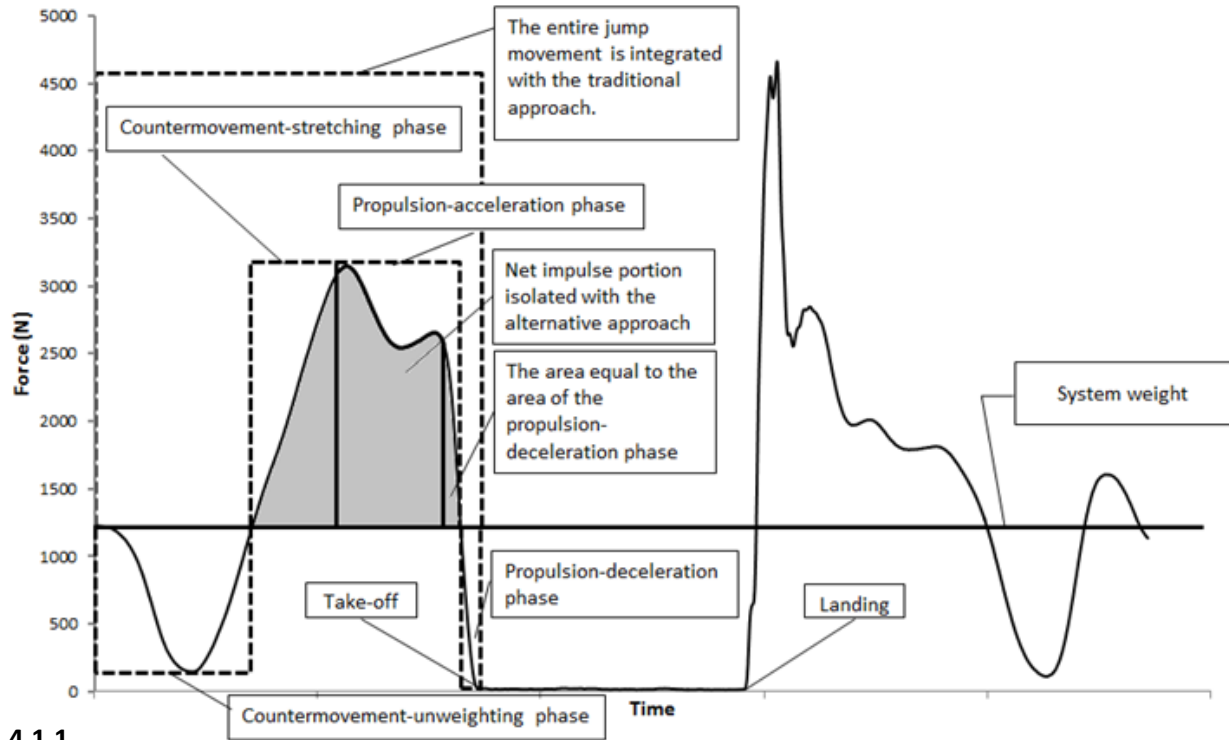
## **Introduction**

**Paragraph 1.** Vertical jumping is a common mode of testing used in sport science to assess one's explosiveness of the lower extremity (3, 5-8, 14, 18, 19). Jump testing is easy, involves minimum risk to perform, and requires minimum familiarization (16, 17). Jumping can be manipulated to assess explosiveness under different levels of resistance (4), may allow for some assessment of one's stretch-shortening cycle function (13), and is often a direct measurement of performance in sports involving jumping such as volleyball and basketball.

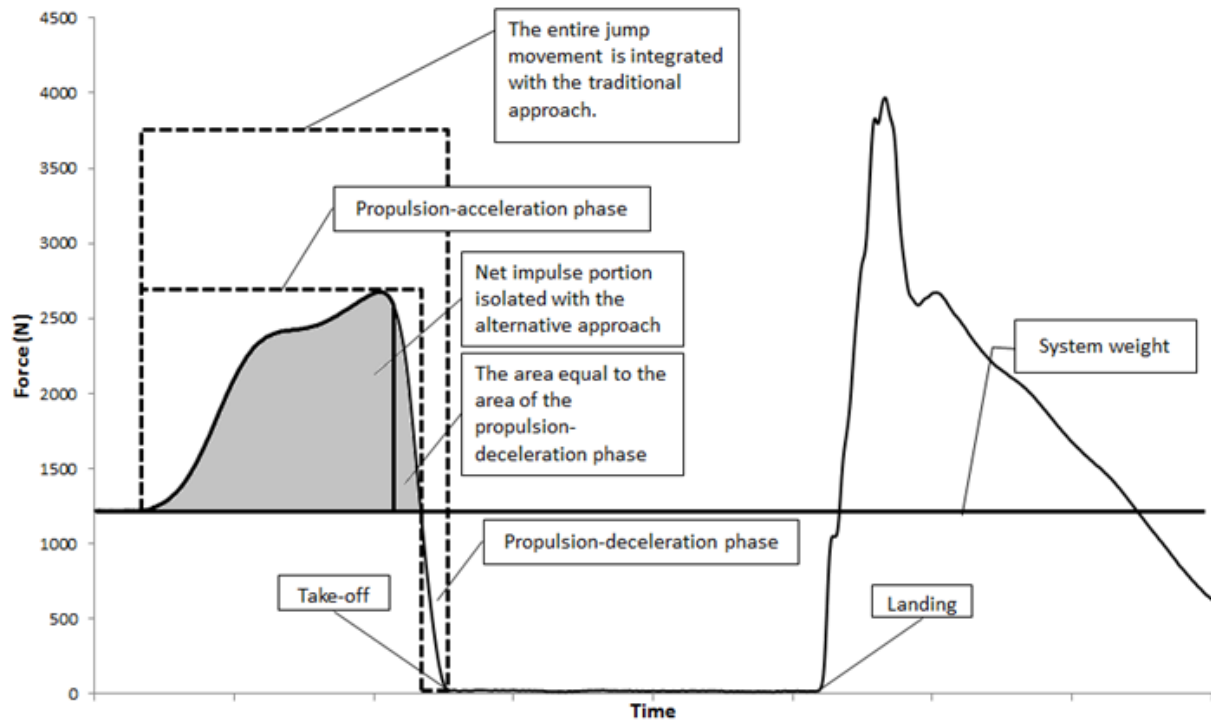
**Paragraph 2.** Recently, Cormie et al. reported changes in portions of a force-time curve during the countermovement jump (CMJ) (6). Power training using the CMJ appeared to induce a greater change in the countermovement-unweighting and stretching phases of the CMJ (Figure 4.1.1), compared to strength training using heavy squatting. This was accompanied by no difference between the two types of training in changes in jump height and peak power of the CMJ. This result suggests that changes in a force-time curve may vary depending on the type of training although changes in outcome measures such as changes in jump height and peak power may not differ at least among relatively weak subjects. Moreover, power training resulted in greater changes in sprint time at 20-m, 30-m, and 40-m points during a 40-m sprint and a flying 15-m sprint while strength training only resulted in changes at the 40-m point. These results suggest that changes in the CMJ force-time curve and sprint performance can be related to a degree because the two types of training also appear to have induced different changes in force-time curves. Therefore, although it is an indirect measurement, quantifying changes in a force-time curve while relating to different phases of a vertical jump force-time curve may yield valuable information that can be used to monitor athletes' performance such as training adaptations.

**Paragraph 3.** One meaningful method to quantify changes in a force-time curve may be by identifying a portion of a force-time curve equivalent to net impulse and subsequently quantifying net impulse characteristics based on a portion of net impulse. The impulse-momentum relationship and the laws of constant acceleration together imply that net impulse in vertical jumping in relation to system mass of a jumper is the primary determinant of jump height (9, 10). Therefore, by examining changes in net impulse characteristics, it may be possible to elucidate how a certain type of training affects an individual's vertical jump kinetics to result in observed changes in jump height, and potentially, changes in other explosive movements such as sprinting. Our previous work investigated criterion validity of a method to identify a portion equivalent to net impulse and test-retest reliability of the method as well as of net impulse characteristics (15). The investigated net impulse characteristics were selected based on the notion that changes in these characteristics have a direct influence on net impulse (Figures 4.2.1-4.2.2). However, the influences, on net impulse, of the investigated net impulse characteristics are unclear. One method to investigate the influence of each characteristic on the contribution to net impulse is through the use of a multiple regression analysis by examining a characteristic's contribution to net impulse. However, when a dependent and independent variables are derived from the same source (i.e. the same force-time curves), multicollinearity becomes a problem from the statistical standpoint. Thus, an alternative means is to examine the contributions of the net impulse characteristics to predicting jump height because net impulse in relation to system mass is the determinant of jump height in theory as mentioned above. Thus, the purpose of this study was to investigate a relative contribution of each net impulse characteristic to predicting jump height in collegiate athletes. Moreover, examination of how each characteristic is associated with different levels of jump height may reveal the degree of importance of the

variable to achieve a high level of jump height. Thus, the secondary purpose of the study was to examine how net impulse characteristics differ according to levels of jump height.

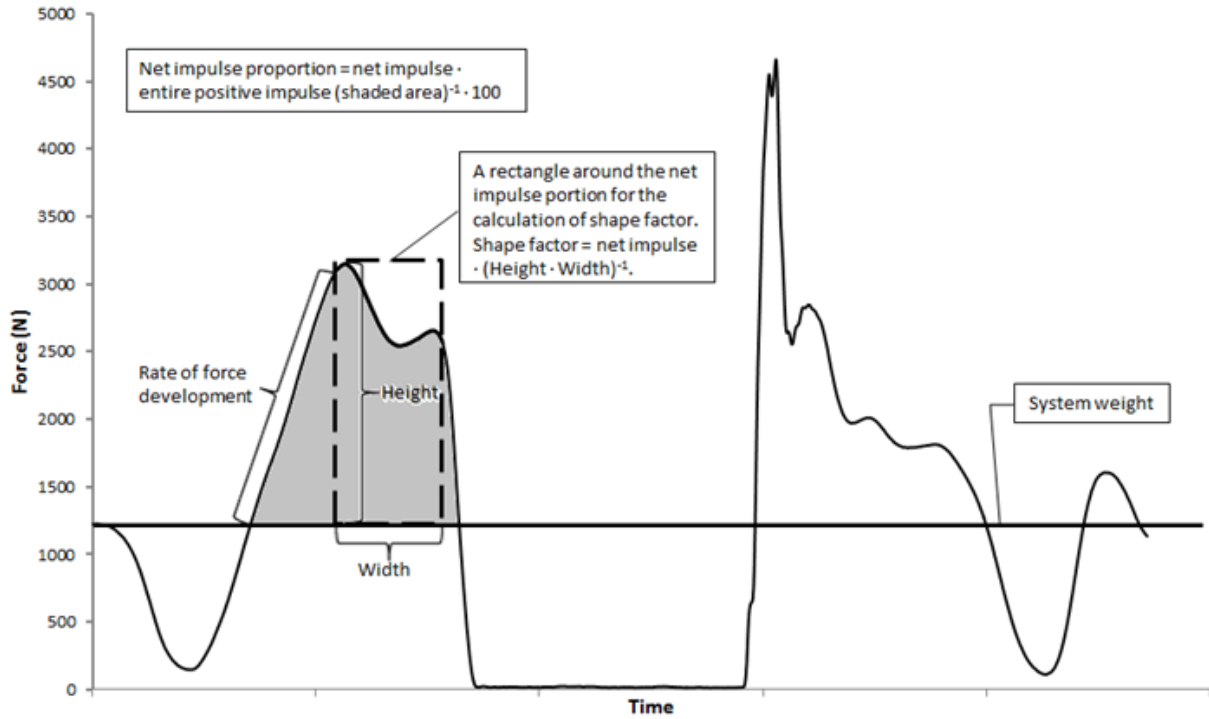


4.1.1

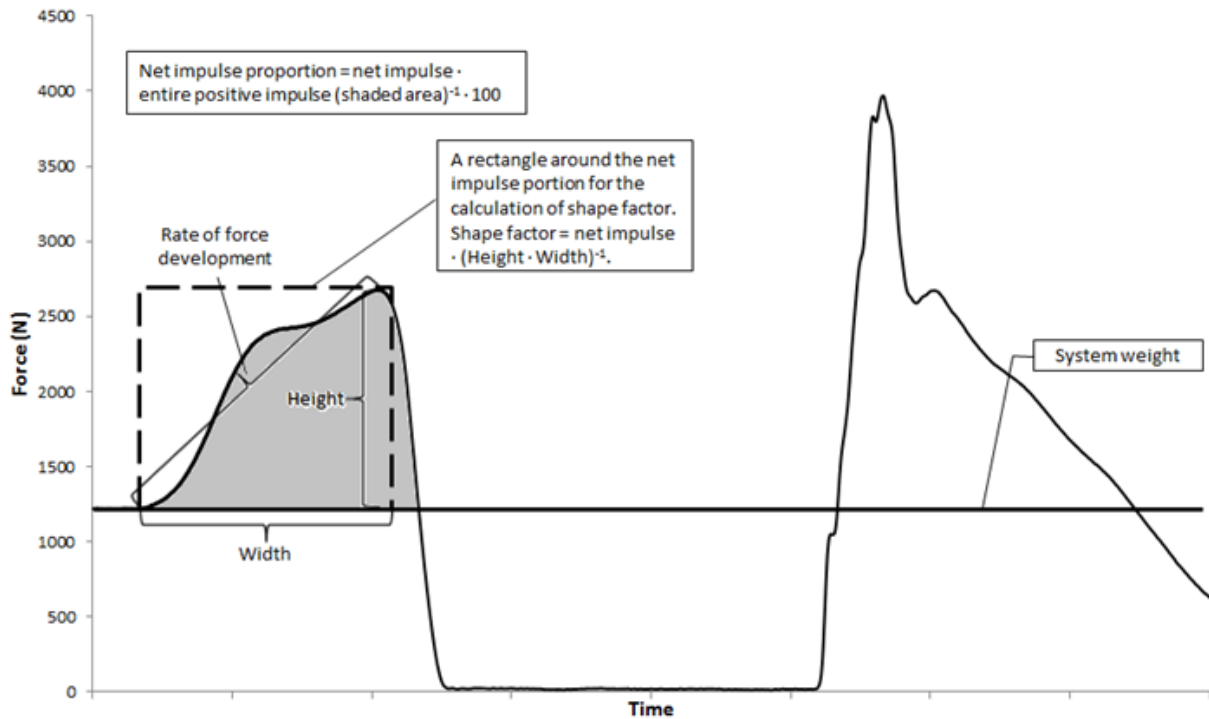


4.1.2

Figures 4.1.1-2 – Phases during the countermovement (4.1.1) and static (4.1.2) jumps. The grey shaded areas indicate the entire positive impulse in relation to system weight.



4.2.1



4.2.2

Figures 4.2.1-2 - Net impulse characteristics of the countermovement (4.2.1) and static (4.2.2) jumps. The grey shaded areas indicate the entire positive impulse in relation to system weight.

## Methods

**Paragraph 4. Participants.** Records of 130 athletes (mean  $\pm$  standard deviation: overall, Age =  $20.8 \pm 2.0$  y, body mass =  $78.8 \pm 16.4$  kg, and height =  $176.4 \pm 10.2$  cm; male, n = 80, age =  $21.1 \pm 2.3$  y, body mass =  $86.6 \pm 14.7$  kg, height =  $181.8 \pm 8.0$  cm; female, n = 50, age =  $20.3 \pm 1.3$  y, body mass =  $66.2 \pm 9.9$  kg, height =  $167.7 \pm 7.0$  cm) were retrieved from the East Tennessee State University Sport and Exercise Science laboratory archive of an on-going athlete's performance monitoring program. The sports the athletes participated in were weightlifting (n = 11, age =  $25.2 \pm 2.1$  y, body mass =  $91.6 \pm 18.8$  kg, and height =  $175.4 \pm 3.1$  cm), baseball (n = 27, age =  $20.6 \pm 2.0$  y, body mass =  $85.5 \pm 8.8$  kg, and height =  $181.6 \pm 6.2$  cm), softball (n = 15, age =  $20.5 \pm 1.1$  y, body mass =  $65.3 \pm 6.1$  kg, and height =  $164.2 \pm 6.0$  cm), track and field throwing (n = 8, age =  $20.4 \pm 1.1$  y, body mass =  $107.1 \pm 20.9$  kg, and height =  $181.7 \pm 10.5$  cm), sprinting (n = 10, age =  $20.7 \pm 1.8$  y, body mass =  $65.2 \pm 9.4$  kg, and height =  $172.1 \pm 8.1$  cm), and jumping events (n = 15, age =  $19.7 \pm 0.9$  y, body mass =  $72.8 \pm 9.5$  kg, and height =  $175.5 \pm 8.1$  cm), men's basketball (n = 11, age =  $20.9 \pm 1.3$  y, body mass =  $91.0 \pm 13.1$  kg, and height =  $190.7 \pm 8.7$  cm), women's volleyball (n = 9, age =  $20.4 \pm 1.1$  y, body mass =  $71.0 \pm 10.4$  kg, and height =  $175.4 \pm 3.1$  cm), men's and women's soccer (n = 12, age =  $20.5 \pm 1.7$  y, body mass =  $79.1 \pm 8.8$  kg, and height =  $181.2 \pm 7.0$  cm and n = 12, age =  $20.4 \pm 0.9$  y, body mass =  $63.0 \pm 7.4$  kg, and height =  $165.5 \pm 6.1$  cm, respectively). All these athletes, except for the weightlifters, were competitive at the National Collegiate Athletic Association Division-I level. The weightlifters were competitive at the sport's national collegiate level or higher. All athletes were considered in total to investigate contributions of the net impulse characteristics, and the entire sample was divided into 5 groups of 26 athletes to examine how each contributing characteristic is associated with levels of jump height. The grouping was based on jump height

rankings of the CMJ and SJ (i.e. the athlete with the greatest jump height was ranked number one) such that the top 26 athletes were grouped together as Very high, the next 26 as High, the middle 26 as Medium, the 26 immediately below Medium as Low, and the remaining 26 as Very low. Because athletes were ranked differently between the two jump types, each of the five groups consisted of slightly different athletes between the two jump types. All athletes read and signed informed consent documents prior to participating in this study. This study was approved by the Institutional Review Board of East Tennessee State University.

**Paragraph 5. Testing procedure.** A standardized warm-up and testing procedures have been described previously (12). Briefly, the warm-up consists of 20 jumping jacks followed by a set of five dynamic mid-thigh pulls with an unloaded 20-kg barbell and three sets of mid-thigh pulls with 60 kg for males and 40 kg for females. Following the warm-up, the jump test begins with the SJ from a 90-degree knee angle with no load (a PVC pipe). Athletes perform a minimum of two jumps unless a false SJ (i.e. preliminary dipping) is recorded. Following the SJ, the CMJ is performed also with no load and the athlete's preferred countermovement depth again for a minimum of two jumps.

**Paragraph 6. Variable calculations.** Calculations of net impulse and its characteristics have been described previously (15) and in Figures 4.2.1-4.2.2. In order to consider a relationship between net impulse height and system mass, net impulse height was divided by system mass and was termed relative net impulse height. Furthermore, our previous work showed that test-retest reliability of these variables was sufficient for this investigation except for shape factor for the SJ, which showed an intraclass correlation coefficient of 0.71 (95% confidence interval: 0.05-0.91) (15). In order to ensure that shape factor is sufficiently reliable

for this study, intraclass correlation coefficient was calculated with this study's data and was 0.80 (95% confidence interval: 0.71-0.86). Jump height was estimated from flight time (1-3).

**Paragraph 7. Testing devices and analysis program.** All jumps were performed on a force plate (0.91 m x 0.91 m, Rice Lake Weighing Systems, Rice Lake, WI, USA). Vertical ground reaction force was sampled at 1000 Hz. Data analyses were performed using a program designed with LabVIEW (ver. 2010, National Instruments, Austin, TX, USA). A digital low-pass Butterworth filter with a cutoff frequency of 10 Hz was used to remove electrical noise.

**Paragraph 8. Statistical analyses.** To investigate contributions of the net impulse characteristics for predicting jump height, a multiple regression analysis was performed for each of the two jump types with jump heights being the dependent variables and the five net impulse characteristics being independent variables. The stepwise procedure was used with the inclusion and exclusion criteria of  $p \leq 0.05$  and  $\geq 0.10$ , respectively. Pearson product-moment correlation coefficients were used to ensure the premise that net impulse in relation to system mass predicted jump height. To investigate associations of the net impulse characteristics with levels of jump height, the five groups were compared using a one-way analysis of variance. Holm's simple sequentially rejective test (11) was used to adjust the critical p value from  $p \leq 0.05$  in order to control for an increase in the type I error rate because multiple analyses of variance had to be performed. All statistical analyses were performed using The Predictive Analytics Software version 19 (SPSS: An IBM company, New York, NY).

## **Results**

**Paragraph 9. Contributions to predicting jump height.** Pearson product-moment correlation coefficients between jump height and net impulse in relation to system mass were  $r = 0.98$  for the CMJ and  $r = 0.97$  for the SJ ( $p < 0.0001$  for both). The multiple regression analysis



found three out of the five CMJ net impulse characteristics (relative net impulse height, net impulse width, and shape factor) together to explain 83% of jump height variance ( $R = 0.91$ , adjusted  $R^2 = 0.83$ , and standard error of estimate = 0.031 m). Means and standard deviations of the examined variables for the CMJ were  $0.328 \pm 0.076$  m for jump height,  $200.63 \pm 51.05$  N·s for net impulse,  $1114.71 \pm 334.95$  N for net impulse height,  $14.00 \pm 2.89$  N·kg<sup>-1</sup> for relative net impulse height,  $221.40 \pm 36.79$  ms for net impulse width,  $6484.38 \pm 3233.39$  N·s<sup>-1</sup> for rate of force development,  $0.84 \pm 0.09$  for shape factor, and  $62.35 \pm 3.14$  % for net impulse proportion. For the SJ, all the net impulse characteristics together were found to explain 90% of net impulse variance ( $R = 0.95$ , adjusted  $R^2 = 0.90$ , and standard error of estimate = 0.019 m). Means and standard deviations of the examined variables for the SJ were  $0.286 \pm 0.060$  m for jump height,  $187.73 \pm 46.88$  N·s for net impulse,  $991.94 \pm 263.37$  N for net impulse height,  $12.53 \pm 2.34$  N·kg<sup>-1</sup> for relative net impulse height,  $336.04 \pm 52.18$  ms for net impulse width,  $3529.28 \pm 1499.91$  N·s<sup>-1</sup> for rate of force development,  $0.58 \pm 0.06$  for shape factor, and  $91.47 \pm 1.58$  % for net impulse proportion. Based on the standardized beta coefficients, relative net impulse height had the greatest contribution while shape factor had the lowest for the CMJ (Table 4.1). Similarly, for the SJ, relative net impulse height had the greatest contribution while rate of force development had the lowest contribution (Table 4.1).

**Paragraph 10. Associations with levels of jump height.** Jump heights of the five groups are presented in Table 4.2. Results of the one-way analyses of variance showed statistical differences only for relative net impulse height ( $p < 0.0001$  and partial  $\eta^2 = 0.36$ ) for the CMJ (Figures 4.1.1-4.1.5). For the SJ, the results showed statistical differences for relative net impulse height ( $p < 0.0001$  and partial  $\eta^2 = 0.52$ ), net impulse width ( $p = 0.006$  and partial  $\eta^2 = 0.11$ ), rate

of force development ( $p < 0.0001$  and partial  $\eta^2 = 0.40$ ), and net impulse proportion ( $p < 0.0001$  and partial  $\eta^2 = 0.71$ ) (Figures 4.2.1-4.2.4).

Table 4.1 – Multiple regression analysis coefficients

Jump type	Variables	Coefficients			p value
		Unstandardized B	SEE	Standardized Beta	
CMJ	Constant	-1.448	0.085	N/A	<0.0001
	Relative net impulse height (N)	0.039	0.002	1.479	<0.0001
	Net impulse width (ms)	0.003	0.0002	1.278	<0.0001
	Shape factor	0.771	0.048	0.873	<0.0001
SJ	Constant	-1.601	0.146	N/A	<0.0001
	Relative net impulse height (N)	0.038	0.003	1.461	<0.0001
	Net impulse width (ms)	0.001	$9.067 \cdot 10^{-5}$	1.115	<0.0001
	Rate of force development ( $N \cdot s^{-1}$ )	$-5.531 \cdot 10^{-6}$	$2.605 \cdot 10^{-6}$	-0.138	0.036
	Shape factor	0.89	0.067	0.907	<0.0001
	Net impulse proportion (%)	0.005	0.002	0.140	0.015

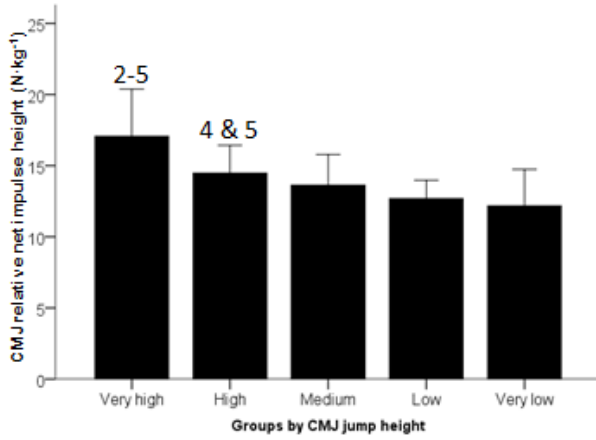
SEE = standard error of estimate.

Table 4.2 – Grouping based on jump height

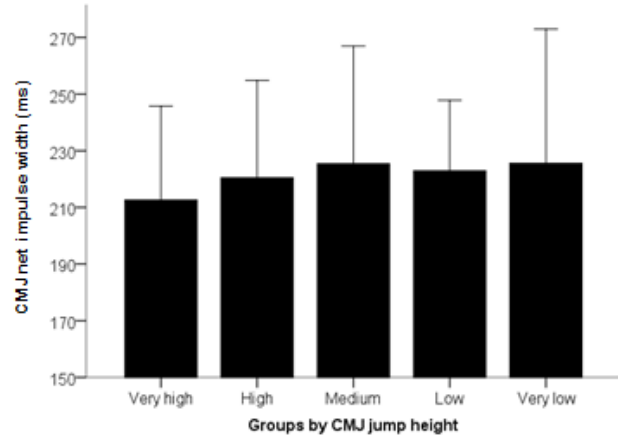
Groups	Countermovement jump height (m)			Static jump height (m)		
	Mean $\pm$ SD	Minimum	Maximum	Mean $\pm$ SD	Minimum	Maximum
Very high	$0.438 \pm 0.036$	0.390	0.529	$0.371 \pm 0.028$	0.336	0.439
High	$0.368 \pm 0.011$	0.348	0.388	$0.319 \pm 0.008$	0.308	0.332
Medium	$0.329 \pm 0.014$	0.304	0.348	$0.287 \pm 0.114$	0.268	0.307
Low	$0.276 \pm 0.015$	0.253	0.304	$0.249 \pm 0.010$	0.232	0.266
Very low	$0.227 \pm 0.022$	0.181	0.251	$0.203 \pm 0.020$	0.152	0.232

SD = standard deviation.

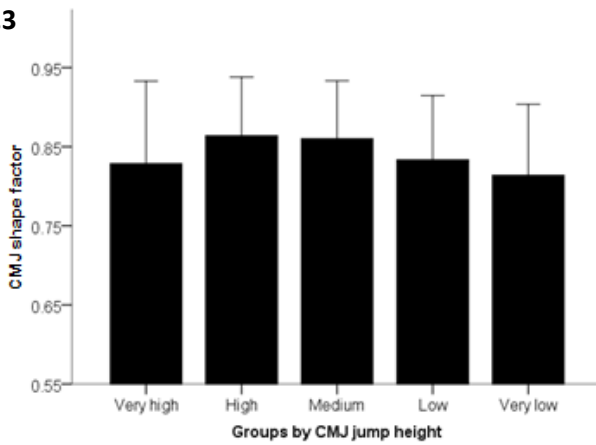
4.3.1



4.3.2

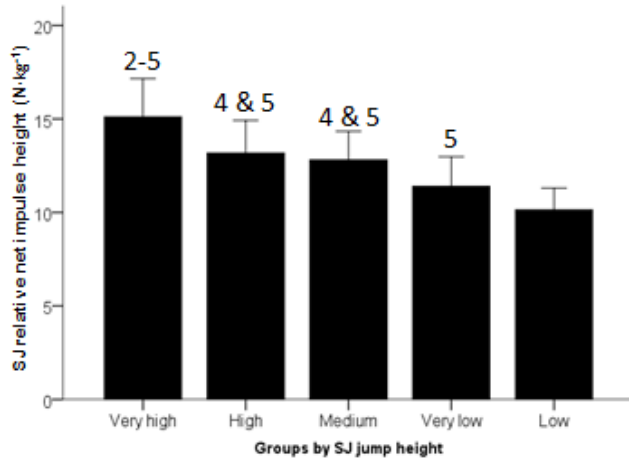


4.3.3

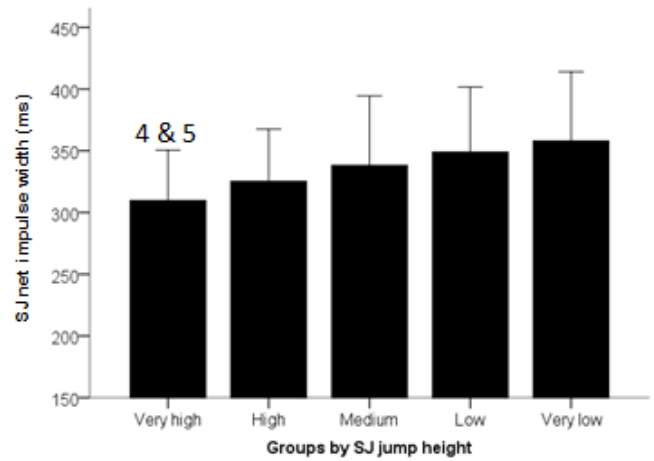


Figures 4.3.1-3 – The countermovement jump group comparisons of contributing net impulse characteristics. 2 = statistical difference from High, 3 = statistical difference from Medium, 4 = statistical difference from Low, and 5 = statistical difference from Very low. No statistical differences were found for net impulse width and shape factor.

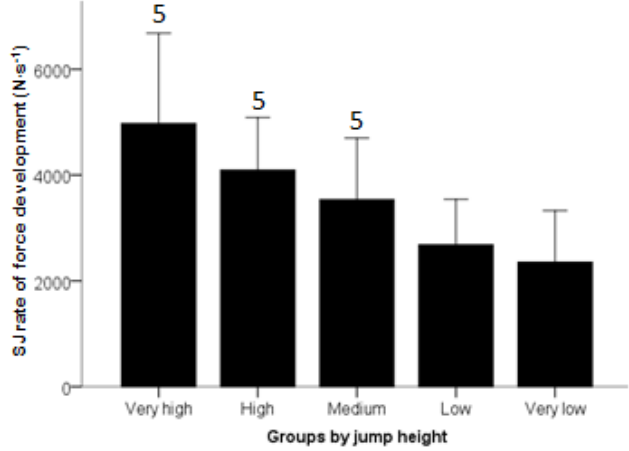
4.4.1



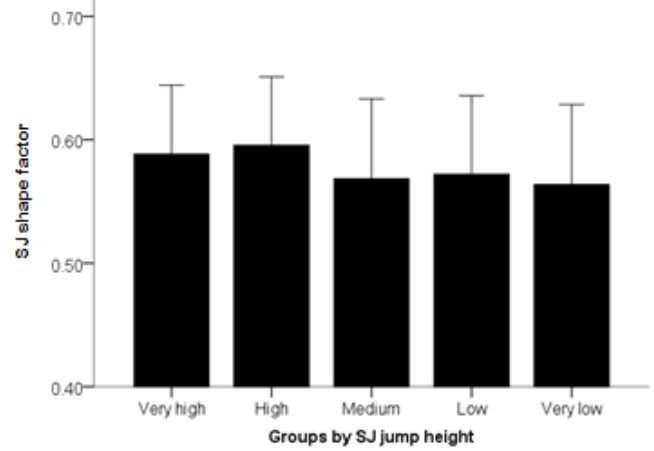
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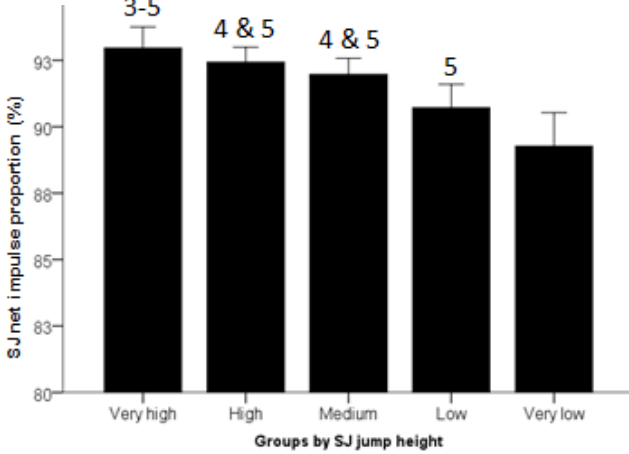
4.4.3



4.4.4



4.4.5



Figures 4.4.1-5 – The static jump group comparisons of contributing net impulse characteristics.

2 = statistical difference from High, 3 = statistical difference from Medium, 4 = statistical

difference from Low, and 5 = statistical difference from Very low. No statistical differences were found for shape factor.

## **Discussion**

**Paragraph 11.** There are three primary findings in this study. 1) Both models of the CMJ and SJ can explain >80% of the variance of jump height. 2) Of the five net impulse characteristics examined, relative net impulse height, net impulse width, and shape factor were found to contribute to predicting CMJ height. On the other hand, all of the five characteristics were found to contribute to SJ height. Moreover, relative net impulse height makes the greatest contribution to predicting jump height in both jumps. 3) Relative net impulse height is the only characteristic that can differentiate some levels of jump height of the CMJ while relative net impulse height and net impulse proportion are the best predictors for the SJ.

**Paragraph 12.** Although the produced models were found to explain >80% of the jump height variance for both jump types, there appear to be other factors that need to be considered (Table 4.1). In particular, rate of force development and net impulse proportion were not found to make predictive contributions for jump height of the CMJ, suggesting that they shared too much predictive variance. In fact, additions of the two characteristics did not change the R and adjusted R<sup>2</sup> values. Furthermore, the adjusted R<sup>2</sup> = 0.83 suggests that there is still 17% of the CMJ jump height variance left to be explained. Although it may not be possible to produce a regression model that explains 100% of the dependent variable variance, it appears that there are other factors to be considered that could improve the model. These factors may be related to net impulse and/or other aspects of a force-time curve as well as to physiological measurements. Nonetheless, the standardized regression coefficients of the model suggest that relative net impulse height is the greatest contributor among the net impulse characteristics to predicting

jump height of the CMJ. On the other hand, the model of the SJ was able to explain 90% of the jump height variance. Moreover, all of the net impulse characteristics were found to be contributors to predicting jump height. These results indicate that the model of the SJ appears to be better able to predict jump height than that of the CMJ probably in part due to less variability in the movement of the SJ (i.e. less complex than the CMJ). However, there is still 10% of the jump height variance left to be explained. Although it is less likely than the model of the CMJ that there are other factors that might improve the model of the SJ, this does not negate the possibility. In addition, similarly to the CMJ, relative net impulse height was found to be the greatest contributor to predicting jump height of the SJ. Taken together, these findings suggest that relative net impulse height makes the greatest contribution to predicting jump height of both jump types. In addition, because both jump types showed very strong correlations between net impulse in relation to system mass and jump height, it is inferred that the net impulse characteristics found to contribute likely characterize and influence net impulse.

**Paragraph 13.** The group comparisons of jump height levels suggest some characteristics to be better able to distinguish between levels of jump height than the others (Figures 4.3.1-4.3.3 and 4.4.1-4.4.5). Although possible patterns with levels of jump height may be identified, the lack of statistical differences in the group comparisons for net impulse width and shape factor indicates that relative net impulse height is the only variable that likely co-varies with jump height. This finding with the results of the multiple regression analysis points out that an increase in relative net impulse may be a primary mechanism of improving CMJ height.

**Paragraph 14.** Similarly, relative net impulse height was one of the characteristics that was better able to distinguish levels of jump height of the SJ. Net impulse proportion is the other

characteristic that was also better able to distinguish between groups. These characteristics may have greater potential to be used for jump performance monitoring. Although delineations between levels of jump height were not as clear as relative net impulse height and net impulse proportion, net impulse width and rate of force development did show a linear trend that appears to co-vary with levels of jump height. With respect to net impulse width, the observed pattern indicates that shorter net impulse width is associated with higher jump height. This pattern was not observed for the CMJ. This discrepancy can be explained by the difference in the control of the depth from which athletes jumped (i.e. preferred for the CMJ vs. 90-degree knee angle for the SJ). Having the knee angle standardized for the SJ probably helped attenuate the effect of depth on vertical displacement during the propulsion phase by making the vertical displacement more equal among athletes, particularly for those who have similar lower-limb length. With similar vertical displacement then, athletes who produce greater net impulse in relation to system mass should complete much of the propulsion-acceleration phase faster. The fewer statistical differences observed with rate of force development of the SJ may be associated with the characteristic's large inherent variability. Our previous work showed that of the five net impulse characteristics, rate of force development had the greatest inter-session variability (15). Taken together, relative net impulse height and net impulse proportion are suggested to be better indicators of levels of jump height. In addition, greater jump height of the SJ can be postulated to result from increases in relative net impulse height and net impulse proportion, and potentially an increase in rate of force development and a decrease in net impulse width. However, as noted above, there are expected to be other factors that can make contributions to predicting jump height. More research should be conducted before any practical suggestions are made. Furthermore, a lack of statistical differences for a net impulse characteristic in the group

comparisons by jump height levels also means that those characteristics that are less able to distinguish levels of jump height may be markers of other physiological and biomechanical changes even when jump height does not change. Thus, intervention-based studies are needed to examine how a certain intervention influences the net impulse characteristics that were found to contribute to predicting jump height.

**Paragraph 15.** In conclusion, the findings of the study suggest the following. 1) Relative net impulse height, net impulse width, and shape factor are the characteristics that contribute to predicting jump height of the CMJ while all of the five characteristics contribute to predicting jump height of the SJ. Based on the very strong correlations between jump height and net impulse in relation to system mass, it is likely that those characteristics also contribute to net impulse. 2) Of the net impulse characteristics found to contribute, relative net impulse height can be an indicator of levels of jump height for both jumps and net impulse proportion for the SJ. Furthermore, although speculative, the other characteristics found to contribute may be indicators of other factors that may not necessarily be reflected in jump height (i.e. only limited variance is shared). For example, as jump height performance is related to other explosive and/or strength movements such as sprinting (3, 5-8, 14, 18, 19), it is possible that relationships exist with other movements and physiological aspects, such as the stretch-shortening cycle and maximum strength as previous research reported differential changes in portions of a vertical jump force-time curve after strength versus power training (6). Therefore, further exploration of the net impulse characteristics may lead to valuable findings.



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## CHAPTER 5

### **Effects of Training on Net Impulse Characteristics and Force Production Ability – an**

#### **Exploratory Study**

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Congresses: This paper has not been presented in any congresses.

Funding: This study was not funded.

There is no conflict of interest identified.

Acknowledgements: We would like to thank the ETSU Men's soccer team.

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## **Abstract**

**Aim.** To examine: 1) how net impulse (NI) characteristics change when jump height (JH) increases and 2) how changes in force production ability are related to changes in the NI characteristics.

**Methods.** Fifteen male collegiate field soccer players performed the countermovement (CMJ) and static jump (SJ) test and isometric mid-thigh pull test before and after approximately twelve weeks of resistance and soccer-specific field training. NI and its characteristics were measured from the jump test.

**Results.** CMJH, take-off velocity, and NI width statistically increased post-training while shape factor statistically decreased. SJH and NI proportion statistically increased. Isometric peak force statistically increased. Increased isometric force variables at and over 200 ms were positively correlated to increased take-off velocity of the CMJ. Moreover, isometric force variables at and over 300 ms were negatively and positively correlated with NI height and NI width, respectively. There were no statistically significant correlations for the SJ variables with changes in the isometric variables.

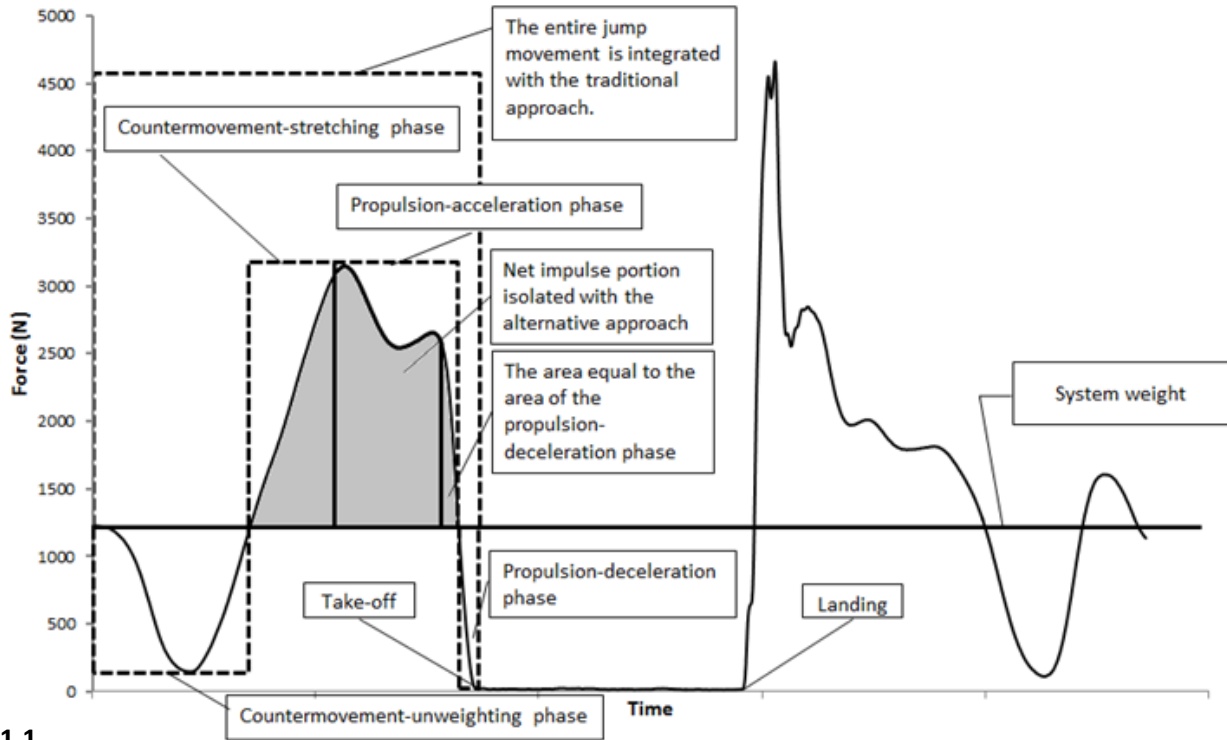
**Conclusion.** A mechanism behind an increase in the CMJH may be an increased countermovement displacement as a result of increased force production ability suggested by the statistically increased NI width without a change in NI height and the positive and negative correlations of the increased force production ability with NI height and width, respectively. A mechanism behind an increase in SJH is an increase in the proportion of the entire positive impulse occupied by net impulse. More research is needed to examine relationships between the NI characteristics and other factors.

## Introduction

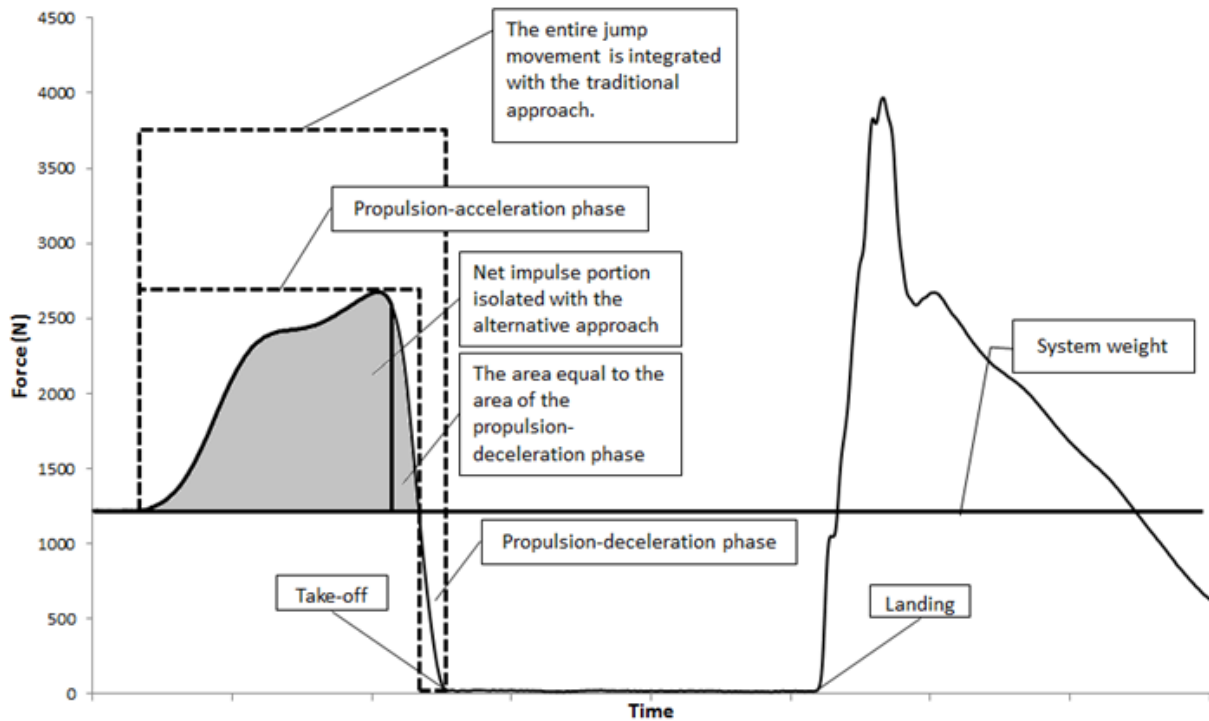
The vertical countermovement and static jumps are two common movements that are utilized as assessments and/or training tools in athletic settings. Common variables to be examined are jump height, peak force, peak power, and peak velocity among others. Although changes in these variables are likely to indicate performance improvements in jumping as well as other explosive movements such as sprinting<sup>1,2,3</sup>, research on changes in force-time curves of the countermovement and static jumps and how those changes influence commonly examined jump variables is scarce. Changes in force-time curves may provide mechanistic insight into how observed improvements are achieved because the majority of commonly measured variables are thought to rely on how force is produced (e.g. magnitude, rate, and coordination).

Cormie and colleagues conducted several studies examining changes in force-time curves of the countermovement jump as a result of either power (the countermovement jump with no load or loads ranging from 0-30% of the squat 1RM) or strength training<sup>4,5,6,7,8</sup>. Their results collectively suggest the following along with increased jump height. 1) The kinetics (minimum force and average force) and thus the force-time curve area of the countermovement-unweighting phase (Figures 5.1.1-5.1.2) decrease (i.e. increases in absolute values). These decreases are reflected in the kinetics of the countermovement-stretching phase as increases in the slope of rising force (e.g. rate of force development) and in the corresponding area of the force-time curve<sup>4,5</sup> because the area of the countermovement-unweighting phase is equal to that of the countermovement-stretching phase<sup>9</sup>. However, these changes appear to be greater after power training compared to strength training<sup>4</sup>. 2) Peak force increases<sup>4,5,6,7</sup> even when it is divided by body mass, suggesting that the force-time curve of the countermovement jump becomes taller. 3) The shape of the area in a force-time curve that corresponds to net impulse appears to change as

jump height increases. For example, their results generally appear to suggest that the first peak shows a greater increase compared to the second peak after power or strength training<sup>4,5</sup> (See Figure 5.2.1 for the two peaks). Along with these changes, differential adaptations in sprinting<sup>4,7</sup>, muscle cross-sectional area<sup>4</sup>, strength<sup>4</sup>, and muscle activations<sup>4,7</sup>, have been reported depending on types of training (i.e. strength vs. power training)<sup>4</sup> and initial strength levels<sup>7</sup>.



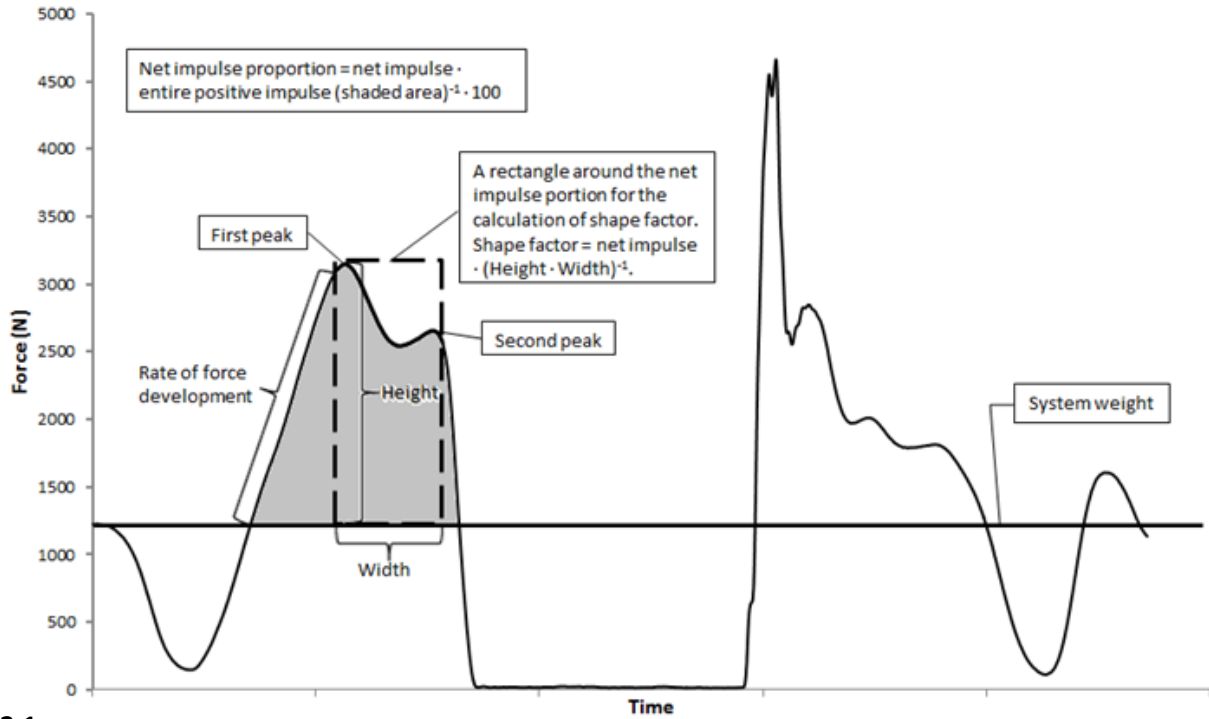
5.1.1



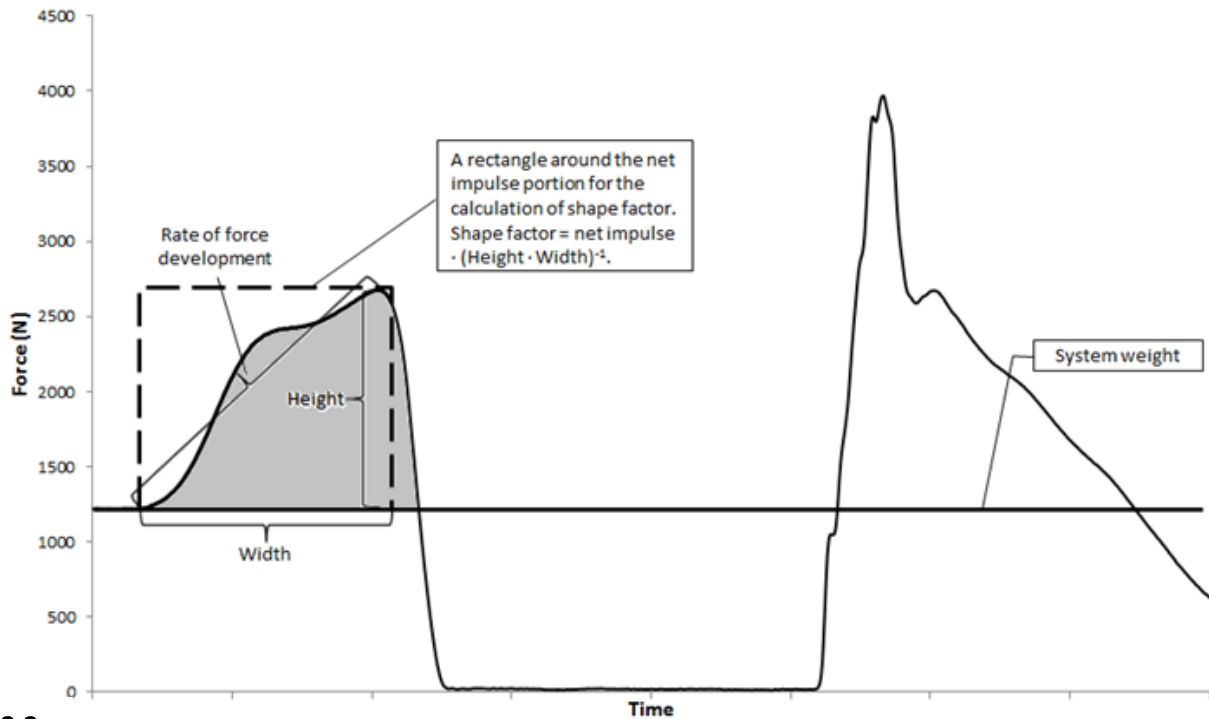
5.1.2

Figures 5.1.1-.2. Phases during the countermovement (5.1.1) and static (5.1.2) jumps. The grey shaded areas indicate the entire positive impulse in relation to system weight.





5.2.1



5.2.2

Figures 5.2.1-2 - Net impulse characteristics of the countermovement (5.2.1) and static (5.2.2) jumps. The grey shaded areas indicate the entire positive impulse in relation to system weight.

Although potential changes in the area of a force-time curve that corresponds to net impulse have been observed, attempts to relate changes in force-time curves to net impulse appear to be lacking. Scientific evidence<sup>10, 11</sup> as well as its theoretical background<sup>12</sup> point out that net impulse is the primary factor determining jump height when considered in relation to system mass (e.g. body mass + external mass). Consequently, examinations of changes in force-time curves in relation to net impulse can further reveal important data regarding interventions that lead to the observed changes. Previously, we investigated test-retest reliability and contributions, to predicting jump height, of variables in force-time curves of the countermovement and static jumps<sup>13, 14</sup>. These variables were net impulse characteristics and were net impulse height (peak force minus body weight) and width (duration of net impulse), rate of force development (slope of rising force during the countermovement-stretching phase), shape factor (relative portion of a rectangle formed around net impulse), and net impulse proportion (relative portion of the entire positive impulse occupied by net impulse)<sup>13</sup> (Figures 5.2.1-5.2.2). These variables were selected based on the notion that changes in one or more, if not all, of these variables should influence net impulse. The examinations of contributions of the net impulse characteristics showed that net impulse height divided by system mass (relative net impulse height), net impulse width, and shape factor are the characteristics that contribute to countermovement jump height while all of the five characteristics contribute to static jump height. Moreover, a higher level of jump height is associated with greater relative net impulse height for both the countermovement and static jumps and with greater net impulse proportion for the static jump. However, a longitudinal study relating changes in the contributing net impulse characteristics to changes in jump height and in force production ability is lacking. Thus, the purposes of the study were to examine: 1) how the

net impulse characteristics change when jump height increases and 2) how changes in force production ability are related to changes in the net impulse characteristics.

## Materials and Methods

### *Participants*

Fifteen athletes (Age:  $20.2 \pm 1.2$  yr and Height:  $178.6 \pm 7.6$  cm) participated in this study (Table 5.1). They were all male field soccer players who were competitive at the National Collegiate Athletic Association Division-I level during the period of the study. All athletes read and signed informed consent documents prior to participating in this study. This study was approved by the Institutional Review Board of East Tennessee State University.

Table 5.1 – Athletes’ body composition

	Pre-training	Post-training
Body mass (kg)	$78.9 \pm 7.4$	$79.5 \pm 7.2$
% body fat	$10.7 \pm 3.3^*$	$9.3 \pm 3.6$

\*Statistical difference between pre- and post-training.

### *Experimental design*

Athletes were tested in the countermovement and static jumps and isometric mid-thigh pull before and after approximately twelve weeks of training. Training consisted of periodized resistance training (Table 5.2) and soccer-specific field technical, tactical, and metabolic training. There was no control group.

Table 5.2 – Resistance training program

	Mon	Wed	Fri	WK	Sets	Reps
<b>Block 1 (4 weeks) - The first day replaced with pre-testing</b>	Back Squat	Clean pull from floor	Back Squat	<b>1</b>	3	10
	Push Press	Clean pull from power position	Push Press	<b>2</b>	5	10
	Box Jump	Hang power clean from power position	Box Jump	<b>3</b>	3	5
	Incline Press	Straight leg dead lift	Incline Press	<b>4</b>	3	3
	Pull-ups/Lat pull-downs		Pull-ups/Lat pull-downs			
<b>Block 2</b>	Back Squat	Clean grip shoulder shrug	Back Squat	<b>1</b>	5	5
	Push Jerk	Clean pull from knee	Push Jerk	<b>2</b>	3	3
	Short sprints (25 m)*	Power clean**	Short sprints (25 m)*	<b>3</b>	3	2
	Incline Press	Straight leg dead lift	Incline Press			
	Pull-ups/Lat pull-downs		Pull-ups/Lat pull-downs			
Spring break						
<b>Block 3</b>	Back Squat	Clean pull from knee	Back Squat	<b>1</b>	5	5
	Push Jerk	Clean pull from power position	Push Jerk	<b>2</b>	3	2
	Jump Squat	Power clean***	Jump Squat	<b>3</b>	3	2
	Incline Press	Straight leg dead lift	Incline Press	<b>4</b>	3	2
	Pull-ups/Lat pull-downs		Pull-ups/Lat pull-downs			
<b>Block 4</b>	<b>Post-testing</b>					

\*Short sprints – 5 sprints @ 90% of perceived maximum effort for WK1, 4 sprints with perceived maximum effort for WK2, and 3 sprints with maximum effort for WK3. \*\*Power clean – 1 cluster set of 5 repetitions for WK1, 1 cluster set of 3 repetitions for WK2, and 1 cluster set of 2 repetitions for WK3 all after multiple warm-up sets that were progressively incremental. \*\*\*Power clean - 1 cluster set of 5 repetitions for WK1, 1 cluster set of 3 repetitions for WK2, and 1 cluster set of 2 repetitions for WK3 & 4 all after multiple warm-up sets that were progressively incremental

### *Testing procedures*

The testing procedures have been described previously<sup>15</sup>. Briefly, the warm-up consisted of twenty jumping jacks followed by a set of five dynamic mid-thigh pulls with an unloaded 20 kg barbell and three sets of mid-thigh pulls with 60 kg. Following the warm-up, the jump test began with the static jump from a ninety-degree knee angle with no load (a PVC pipe held across the back of the shoulders). Athletes performed a minimum of two jumps unless a false static jump (i.e. dipping or countermovement) was recorded. Following the static jump, the countermovement jump was performed also with no load using the athlete's preferred depth of the countermovement again for a minimum of two jumps. Following the jump testing, the isometric mid-thigh pull testing was performed. This test has been previously used successfully to measure athletes' force production ability (e.g. strength and explosive strength)<sup>2, 15, 16, 17, 18, 19, 20</sup> and isometric peak force has been shown to be correlated to other measures of strength such as squat one repetition maximum (1RM)<sup>2, 20</sup>. Athletes were placed in the power position of the clean (knee angle  $\approx$  125-135 degrees) with their hands fixed to an immovable bar with weightlifting straps and athletic tape. They were given two warm-up trials at 50 and 75% of their perceived maximum effort. Following the warm-up trials, a minimum of two maximum attempts were performed. Three or more attempts were performed if the first two attempts differed by more than 200 N in isometric peak force.

### *Jump Variables Calculations*

Calculations of net impulse and its characteristics have been described previously (Figures 5.2.1-5.2.2)<sup>13</sup>. In addition, net impulse was divided by system mass to obtain take-off velocity in order to examine a relative relationship. Net impulse height was also divided by system mass to account for individual differences in body mass (relative net impulse height).

System mass was determined by converting system weight determined on a force plate apart from the body mass measurement. Jump height was estimated from flight time<sup>3, 21, 22</sup>.

#### *Isometric Mid-thigh Pull Variable Calculations*

From force-time curves of the isometric mid-thigh pull, the following variables were obtained: isometric peak force (the highest instantaneous force value) and isometric time-dependent instantaneous forces and rates of force development during durations that are approximately equal to net impulse width for the countermovement and static jumps. These time dependent-instantaneous forces and rates of force development were measured from the initiation of the isometric pulling movements identified on isometric force-time curves. In addition, the instantaneous force values (i.e. those excluding rates of force development) were scaled to account for differences in body mass using allometric scaling<sup>23</sup>.

#### *Testing Devices and Analysis Program*

Body mass and percent body fat were both measured using BodPod air displacement plethysmography instrumentation (Life Measurement Inc, Concord, CA). All jumps and isometric mid-thigh pulls were performed on a force plate (0.91 m x 0.91 m, Rice Lake Weighing Systems, Rice Lake, WI, USA). Vertical ground reaction force was sampled at 1000 Hz. Data analyses were performed using a program designed with LabVIEW (ver. 2010, National Instruments, Austin, TX, USA). A digital low-pass Butterworth filter with a cutoff frequency of 10 Hz was used to remove electrical noise.

#### *Statistical Analyses*

A paired-sample t-test (two tailed) was used to detect a change from pre- to post-training. Pearson product-moment correlation coefficients were calculated to assess strength of relationships between changes in the examined variables. The critical alpha level was set at  $p \leq$

0.05. Holm's simple sequentially rejective test<sup>24</sup> was used to adjust the critical p value from  $p \leq 0.05$  in order to control for type I error rate because multiple paired-sample t-tests were performed. All the statistical calculations except for a Cohen's d were performed using Statistical Package for Social Science (SPSS) (ver. 18.0, SPSS Inc., Chicago, IL, USA). A Cohen's d was calculated by entering the formulae into Microsoft Office Excel (2007, Microsoft Cooperation, Redmond WA)<sup>25</sup>. The scale of rating for Cohen's d by Hopkins<sup>26</sup> was used to evaluate practical importance of a difference (d < 0.2: trivial; d = 0.2-0.6: small; d = 0.6-1.2: moderate; d = 1.2-2.0: large; d = 2.0-4.0: very large). Also, the scale of rating for Pearson product-moment correlation coefficient by Hopkins<sup>26</sup> was used to evaluate the strength of a relationship (r = 0.0-0.1: trivial, r = 0.1-0.3: small, r = 0.3-0.5: moderate, r = 0.5-0.7: large, r = 0.7-0.9: very large, and r = 0.9-1.0: nearly perfect).

## **Results**

There was a statistical change in percent body fat but not in body mass (Table 5.1). Results of the countermovement jump testing showed that jump height, take-off velocity, and net impulse width statistically increased while shape factor statistically decreased (Table 5.3). The increase in take-off velocity suggests that although net impulse did not change statistically, a ratio of net impulse to system mass increased because take-off velocity was calculated by net impulse divided by system mass. For the static jump, jump height and net impulse proportion showed statistical increases from pre-training (Table 5.4). Contrary to the countermovement jump, take-off velocity only showed a trend towards statistical significance. Correlations between changes in jump height and the net impulse characteristics showed that changes in take-off velocity and in jump height were statistically correlated for both the countermovement and static jumps (Table 5.5). Changes in net impulse and in static jump height were also statistically

correlated. Of all the net impulse characteristics, a change in static jump net impulse proportion was the only characteristic that had a statistical correlation with a change in static jump height. In the isometric mid-thigh pull testing, as described in the methods section, isometric time-dependent kinetic variables were measured and calculated based on net impulse width. As net impulse width was approximately 200 and 300 ms on average for the countermovement and static jumps, respectively (Tables 5.3 and 5.4), the isometric time-dependent kinetic variables were calculated during the time windows of 200 and 300 ms. Thus, the isometric time-dependent kinetic variables were absolute and allometrically-scaled forces at 200 and 300 ms and rates of force development over 200 and 300 ms from the initiation of isometric pull. Results of the isometric mid-thigh pull testing showed that peak force and allometrically-scaled peak force showed statistically increased from pre-training (Table 5.6).



Table 5.3 – Results of the countermovement jump testing.

	Countermovement jump variables (Mean $\pm$ SD)			p value	d value	1- $\beta$
	Pre-training	Post-training	Change			
Jump height (m)	0.337 $\pm$ 0.052	0.36 $\pm$ 0.049	0.024 $\pm$ 0.024*	0.004	0.47	0.89
Net impulse (N·s)	208.97 $\pm$ 20.38	209.7 $\pm$ 21.65	1.95 $\pm$ 9.49	0.747	0.04	0.06
Take-off velocity (m·s <sup>-1</sup> )	2.58 $\pm$ 0.19	2.64 $\pm$ 0.2	0.08 $\pm$ 0.09*	0.010	0.32	0.79
Net impulse height (N)	1344.04 $\pm$ 364.27	1283.98 $\pm$ 236.51	-44.61 $\pm$ 173.96	0.204	0.20	0.24
Relative net impulse height (N·kg <sup>-1</sup> )	16.55 $\pm$ 4.02	16.20 $\pm$ 2.84	-0.36 $\pm$ 2.00	0.498	0.10	0.10
Net impulse width (ms)	192.3 $\pm$ 44.39	206.37 $\pm$ 40.36	14.19 $\pm$ 15.67*	0.007	0.34	0.84
Shape factor	0.86 $\pm$ 0.06	0.82 $\pm$ 0.09	-0.04 $\pm$ 0.06*	0.007	0.54	0.84

A p value from a paired-sample t test is reported in the column p value along with effect sizes (d value) and statistical power values

(1- $\beta$ ). \* indicates a statistical difference between pre-training and post-training.

Table 5.4 – Results of the static jump testing.

	Static jump variables (Mean $\pm$ SD)			p value	d value	1- $\beta$
	Pre-training	Post-training	Change			
Jump height (m)	0.297 $\pm$ 0.04	0.313 $\pm$ 0.038	0.021 $\pm$ 0.025*	0.021	0.42	0.68
Net impulse (N·s)	195.05 $\pm$ 15.55	195.68 $\pm$ 18.27	3.43 $\pm$ 14.28	0.844	0.04	0.05
Take-off velocity (m·s <sup>-1</sup> )	2.41 $\pm$ 0.14	2.47 $\pm$ 0.15	0.08 $\pm$ 0.13	0.062	0.43	0.47
Net impulse height (N)	1094.8 $\pm$ 168.51	1107.92 $\pm$ 114.78	10.69 $\pm$ 137.48	0.741	0.09	0.06
Relative net impulse height (N·kg <sup>-1</sup> )	13.54 $\pm$ 2.02	14.03 $\pm$ 1.84	0.49 $\pm$ 1.83	0.315	0.26	0.16
Net impulse width (ms)	301.83 $\pm$ 35.33	308.67 $\pm$ 38.7	7.75 $\pm$ 41.74	0.571	0.19	0.08
Rate of force development (N·s <sup>-1</sup> )	4273.7 $\pm$ 1353.9	4156.48 $\pm$ 699.93	-113.34 $\pm$ 1143.13	0.724	0.11	0.06
Shape factor	0.6 $\pm$ 0.05	0.58 $\pm$ 0.08	-0.01 $\pm$ 0.06	0.276	0.31	0.19
Net impulse proportion (%)	91.99 $\pm$ 0.91	92.4 $\pm$ 0.85	0.9 $\pm$ 2.08*	0.016	0.48	0.72

A p value from a paired-sample t test is reported in the column p value along with effect sizes (d value) and statistical power values

(1- $\beta$ ). \* indicates a statistical difference between pre-training and post-training.

Table 5.5 – Correlations between changes in jump height and the net impulse characteristics.

		Changes in jump height	
		Countermovement jump	Static jump
Changes in net impulse characteristics	Net impulse	0.441	0.792*
	Take-off velocity	0.759*	0.925*
	Net impulse height	-0.396	0.014
	Relative net impulse height	-0.312	-0.056
	Net impulse width	0.319	0.180
	Rate of force development	N/A	-0.021
	Shape factor	0.182	0.217
	Net impulse proportion	N/A	0.754*

\* indicates a statistically significant correlation.

Table 5.6 – Results of the isometric mid-thigh pull testing.

	Isometric mid-thigh pull variables (Mean ± SD)			p value	d value	1-β
	Pre-training	Post-training	Change			
Peak force (N)	4416.35 ± 505.66	4645.62 ± 526.79	297.66 ± 237.57*	< 0.0001	0.46	0.998
Allo. peak force (N·kg <sup>-0.67</sup> )	240.33 ± 25.29	251.5 ± 25.43	14.57 ± 13.16*	0.001	0.46	0.961
Force at 200 ms (N)	2632.03 ± 493.66	2730.61 ± 633.43	130.67 ± 352.03	0.274	0.18	0.186
Force at 300 ms (N)	3089.53 ± 596.96	3180.31 ± 647.42	87.84 ± 321.76	0.264	0.15	0.192
Allo. force at 200 ms (N·kg <sup>-0.67</sup> )	142.9 ± 26.19	147.64 ± 33.91	6.22 ± 18.27	0.326	0.16	0.158
Allo. force at 300 ms (N·kg <sup>-0.67</sup> )	168.06 ± 33.54	172.05 ± 34.81	3.76 ± 17.32	0.384	0.12	0.134
Rate of force development over 200 ms (N·s <sup>-1</sup> )	7514.35 ± 2033.71	7876.04 ± 2752.27	543.78 ± 1913.31	0.469	0.15	0.107
Rate of force development over 300 ms (N·s <sup>-1</sup> )	6534.55 ± 1688.54	6749.67 ± 1833.28	219.72 ± 1173.05	0.488	0.13	0.102

Allo. peak force = allometrically-scaled peak force, and allo. force at 200 and 300 ms = allometrically-scaled force at 200 and 300 ms.

A p value from a paired-sample t test is reported in the column p value along with effect sizes (d value) and statistical power values

(1-β). \* indicates a statistical difference between pre-training and post-training.

Correlations between changes in the countermovement jump variables and changes in the isometric mid-thigh pull variables showed a few statistically significant results (Table 5.7). First, changes in countermovement net impulse and take-off velocity were statistically correlated with isometric force and rate of force development during 200 ms. Second, for the countermovement jump net impulse characteristics, changes in the isometric force variables at 300 ms were statistically negatively correlated with changes in net impulse height. On the other hand, changes in the isometric force variables at 300 ms were generally positively correlated with changes in countermovement net impulse width. However, there were no statistically significant correlations between changes in the static jump variables and in the isometric mid-thigh pull variables (Table 5.8).

Table 5.7 – Correlations between changes in countermovement jump variables and changes in isometric mid-thigh pull variables.

		Changes in isometric mid-thigh pull variables							
		PF	aPF	F200	F300	aF200	aF300	RFD200	RFD300
Changes in countermovement jump variables	Jump height	0.399	0.434	0.338	0.305	0.371	0.334	0.439	0.411
	Net impulse	0.095	-0.196	0.528*	0.201	0.430	0.075	0.413	0.111
	Take-off velocity	0.309	0.234	0.520*	0.482	0.520*	0.465	0.524*	0.481
	Net impulse height	-0.310	-0.287	-0.307	-0.544*	-0.304	-0.528*	-0.347	-0.557*
	Relative net impulse height	-0.276	-0.166	-0.320	-0.465	-0.284	-0.403	-0.320	-0.438
	Net impulse width	0.306	0.178	0.511*	0.634*	0.474	-0.560*	0.484	0.577*
	Shape factor	0.122	0.013	-0.023	-0.155	-0.049	-0.167	-0.043	-0.158

PF = peak force, aPF = allo. peak force, F200 = force at 200 ms, F300 = force at 300 ms, aF200 = allo. force at 200 ms, aF300 = allo.

force at 300 ms, RFD200 = rate of force development over 200 ms, and RFD300 = rate of force development over 300 ms. \* indicates

a statistically significant correlation.

Table 5.8 – Correlations between changes in static jump variables and changes in isometric mid-thigh pull variables.

		Changes in isometric mid-thigh pull variables							
		PF	aPF	F200	F300	aF200	aF300	RFD200	RFD300
Changes in static jump variables	Jump height	0.283	0.060	0.269	0.176	0.200	0.095	0.195	0.104
	Net impulse	0.075	-0.264	0.379	0.149	0.259	0.002	0.213	-0.005
	Take-off velocity	0.235	-0.024	0.375	0.329	0.294	0.226	0.258	0.202
	Net impulse height	0.282	0.151	-0.088	-0.174	-0.123	-0.209	-0.166	-0.244
	Relative net impulse height	0.325	0.255	-0.135	-0.137	-0.145	-0.144	-0.185	-0.188
	Net impulse width	-0.397	-0.425	0.073	0.378	0.044	0.332	0.042	0.300
	Rate of force development	0.314	0.272	-0.148	-0.276	-0.153	-0.272	-0.173	-0.281
	Shape factor	0.192	0.201	0.196	-0.151	0.208	-0.132	0.241	-0.060
	Net impulse proportion	0.133	-0.121	0.355	0.169	0.265	0.055	0.242	0.066

PF = peak force, aPF = allo. peak force, F200 = force at 200 ms, F300 = force at 300 ms, aF200 = allo. force at 200 ms, aF300 = allo. force at 300 ms, RFD200 = rate of force development over 200 ms, and RFD300 = rate of force development over 300 ms. \* indicates a statistically significant correlation.

## Discussion

The purposes of the study were to examine 1) how the net impulse characteristics change when jump height increases and 2) how changes in force production ability are related to changes in the net impulse characteristics. There are several important findings in this study. 1) An increase in countermovement jump height occurred with an increase in net impulse width and a decrease in shape factor. For the static jumps, an increase in static jump height occurred with a change in net impulse proportion. 2) A mechanism of the improved countermovement jump height appears to be an increase in the countermovement displacement. 3) A mechanism of the improved static jump height appears to be an increase in the proportion of the entire positive impulse (Figure 5.1.2) occupied by net impulse.

The training program undertaken in this study appears to have resulted in an increase in the displacement of the countermovement in the countermovement jump. Although there was no direct measurement of the displacement of the countermovement, this can be speculated from the following. 1) Net impulse width may be positively related to the propulsion phase time (i.e. time from the initiation of the propulsion to take-off) although the propulsion phase time was not measured. An increase in the propulsion phase time is theoretically possible only when a) an effort to jump is decreased without a change in the displacement of the countermovement or b) an effort to jump remains the same but the displacement of the countermovement increases. In fact, Salles et al.<sup>27</sup> reported that the acutely increased displacement of the countermovement and decreased volitional effort to jump both led to an increase in time from the initiation of the countermovement to take-off, which is inferred to have resulted from increased times in both the countermovement and propulsion phases (i.e. a greater displacement to cover or a lower movement velocity over the same displacement). Moreover, Cormie et al. reported an increase in



the displacement of the countermovement as a result of power training consisting of the countermovement jumps with no load<sup>5</sup>. 2) An increase in net impulse height was probably offset by a negative effect of an increase in the displacement of the countermovement. Previous studies<sup>10, 27</sup> suggest that there is an inverse relationship between the displacement of the countermovement and peak force (note that net impulse height is peak force minus system weight). This is also a speculation as there is no direct evidence from this study. However, these two together, with no statistical change in body mass, appear to be able to explain the results of the countermovement jump given increased jump height and take-off velocity without changes in relative net impulse height, which was previously found to be an important factor for higher levels of jump height<sup>14</sup>. Offsetting the potential increase in relative net impulse height can then explain the lack of a statistical correlation between changes in relative net impulse height and jump height. Furthermore, in our laboratory, we observed that stronger athletes appear to jump with the greater magnitude of a countermovement<sup>28</sup>. However, the increase in net impulse width was not found to be statistically correlated to the increase in jump height although the correlation coefficient was positive and moderate<sup>26</sup>.

The decrease in shape factor for the countermovement jump indicates that the shape of net impulse became more like a triangle rather than a rectangle. However, the decrease in shape factor was not found to correlate with an increase in jump height (Table 5.5). This suggests that the observed change in shape factor is an indicator of a change in parameters other than jump height. Although it is not clear what a change in shape factor indicates for the countermovement jump, a decrease in shape factor also suggests the possibility that the difference between the two peaks became greater (i.e. an increase in the first peak was greater than an increase in the second peak) (Figure 5.2.1). Changes in the relationship between the two peaks were also reported by

Cormie et al. after a period of power training consisting of the countermovement jumps performed with maximum effort or strength training consisting of heavy back squatting<sup>4,5</sup>. Because the majority of the positive force (i.e. above system weight) rising to the first peak occurs during the countermovement-stretching phase, the first peak likely depends on the momentum of the center of mass of the system created by the countermovement and the ability to quickly decelerate to initiate the propulsion phase. Thus, a decrease in shape factor can be attributed to an increase in the negative impulse during the countermovement-unweighting phase, which subsequently increases the positive impulse during the countermovement-stretching phase. This along with the possible increase in the displacement of the countermovement suggests the possibility that the training undertaken in this study influenced the kinetic and kinematic profiles of the countermovement and contributed to the increased jump height. In fact, Cormie et al. also showed increases in force, velocity, and displacement during the countermovement-unweighting phase as a result of power or strength training<sup>4</sup>. However, they also reported disappearance of the two peaks as a result of power training for individuals who had a greater level of initial strength compared to individuals who had a lower level<sup>7</sup>. This may be due to the process of averaging individual force-time curves. However, more research is certainly needed to draw more clear conclusions.

A mechanism behind an increase in the static jump height is an increase in net impulse proportion (i.e. the increased proportion of the entire positive impulse that net impulse occupies). Of all the net impulse characteristics examined for the static jump, net impulse proportion was the only characteristic found to have a statistical change from pre-training concomitant with an increase in jump height. This change in net impulse proportion was also statistically positively correlated to the change in jump height (Table 5.5). Interestingly, there was no statistical change

in relative net impulse height, which was previously found to be one of two important factors for higher static jump height (the other factor was net impulse proportion)<sup>14</sup>. Because the depth of the preliminary squat was standardized at a knee angle of 90 degrees and each jump was monitored for a preliminary countermovement, it is less likely that an increase in the depth offset an increase in relative net impulse height. The lack of a statistical change in net impulse width also supports no change in the preliminary squat depth, although it is indirect evidence. Furthermore, there was no statistical change in net impulse. The lack of a change in the preliminary squat depth and in net impulse and the increase in net impulse proportion then point out that there was a proportional reduction in the positive impulse at the end of the propulsion acceleration phase that is equal in area to the negative impulse during the propulsion-deceleration phase (Figure 5.1.2). This indicates that the training program implemented in this study caused the athletes to achieve a greater velocity prior to the deceleration due to gravity during the period of the positive impulse at the end of the propulsion-acceleration phase. Although a change in take-off velocity (i.e. the ratio of net impulse to system mass) was not found to be statistically significant (Table 5.4), a trend towards statistical significance was observed (Table 5.4) along with an almost perfect correlation coefficient between changes in take-off velocity and in jump height (Table 5.5). The disagreement between changes in jump height and in take-off velocity of the static jump may be due more to error associated with methodological differences (i.e. jump height from flight time versus take-off velocity from net impulse). Taken together, the results of the static jump indicate that a mechanism of an increase in jump height is an increase in net impulse proportion: that is, a greater velocity prior to the propulsion-deceleration phase leading to a speculated proportional decrease in the area of the propulsion-deceleration phase.

Results of the correlations of changes in the isometric mid-thigh pull testing with changes in the countermovement jump net impulse characteristics suggest the following. 1) Changes in force production ability during the duration of net impulse width (i.e. 200 ms in this study) are related to changes in net impulse and take-off velocity of the countermovement jump. 2) In contrast, changes in force production ability beyond the duration of net impulse width are related to changes in net impulse height, width, and proportion. These findings indicate that for jump performance such as net impulse and take-off velocity, force production ability over the duration of net impulse width is more important in the countermovement jump while for some net impulse characteristics, force production ability beyond the duration of net impulse width is more important. Furthermore, the lack of statistically significant correlations with absolute or allometrically-scaled peak force suggests that in the sample of athletes examined in this study, a change in the ability to produce force within a certain time window was more important for changes in net impulse height, width, and proportion. However, this does not mean that the maximum force production ability is not important in jump performance because previous studies reported that stronger athletes are more likely to perform better in vertical jumping<sup>1, 2, 3, 16, 17, 20</sup>. 3) An increase in force production ability may cause an individual to increase the displacement of the countermovement. As mentioned above, the increased countermovement jump height may be attributable to an increase in the displacement of the countermovement. If this speculation is true, the negative relationships found between changes in isometric force at 300 ms and rate of force development over 300 ms and in net impulse height can also be explained. That is, a greater increase in force production ability at and over 300 ms allowed an individual to increase the displacement of the countermovement, which in turn led to an increase in net impulse height to be offset at least partially. In addition, the positive relationships found

between changes in net impulse width and the similar isometric force variables at and over 300 ms further provide support for the relationship between the increase in force production ability and the increase in the displacement of the countermovement.

For the static jump, no statistically significant correlations were found between changes in any of the static jump variables and in any of the isometric variables. The strongest correlation found was a negative moderate relationship between changes in allometrically-scaled isometric peak force and in net impulse width. Although not statistically significant, this negative correlation indicates that, as an athlete increases the maximum force production ability in relation to his or her body mass, net impulse width becomes shorter probably due to an increase in acceleration and resulting velocity during the propulsion phase of the static jump given no change in the preliminary squat depth as in this study. However, due to the lack of statistically significant correlations, it is not possible to suggest any relationships or patterns of changes between the net impulse characteristics and the force production ability when jump height increases due to training for the static jump.

### **Conclusions**

The findings of the study suggest the following. 1) A mechanism behind an increase in the countermovement jump height may be to increase the displacement of the countermovement as a result of the increased time-dependent force production ability acquired from training. Increases in the displacement and kinetics of the countermovement in turn appear to offset an increase in net impulse height while increasing net impulse width and decreasing shape factor. A decrease in shape factor makes net impulse appear more like a triangle. The decrease in shape factor also suggests a possible increase in the difference between the two peaks. Thus, the difference between the two peaks may be suggested as a new variable for examination. 2) An

increase in net impulse proportion is a mechanism to increase static jump height. However, changes in the static jump variables were not statistically correlated with changes in any of the isometric force variables. Thus, it is difficult to suggest mechanistic relationships between changes in force production ability and the static jump variables.

To our knowledge, this is the first study examining changes in force-time curves of the countermovement and static jumps in relations to net impulse along with increased force production ability due to training in athletic populations. Furthermore, experimental control that could potentially compromise athletes' performance preparations was kept to minimum to emphasize ecological and thus external validity. Results of the study, however, must be carefully interpreted because of potential interactions between soccer-specific metabolic and tactical and technical training and resistance training. In particular, the lack of statistically significant correlations between changes in the static jump variables and in the isometric force variables in this study does not necessarily mean that an increase in force production ability does not play a role. Previous studies suggest moderate to strong correlations between force production ability measured in different manners (e.g. strength) and jump performance (e.g. jump height and peak power)<sup>1, 2, 3, 16, 17, 20</sup>. In addition, the lack of statistical changes and correlations between changes in the jump and isometric force variables can be due to a few factors such as the length of the training period and training status at the initiation of the study. These factors could have prevented substantial changes (e.g. large effect size:  $d > 1.2$ ), which may be needed to detect measureable changes in many of the net impulse characteristics and the isometric force variables. Moreover, although the design of the study achieves a high degree of ecological validity, more controlled experimental designs to isolate effects of various training regimens should also be useful in relating specific changes in the net impulse characteristics to types of training,

physiological changes, and performance in other movements such as sprinting. Therefore, future studies should consider utilizing both experimental designs that retain ecological validity but have a degree of control such that changes in the net impulse characteristics can be related to changes in other measures. However, control should be used with athletes' performance in consideration so that their performance will not be compromised. For example, long-term examination of weightlifters as they become more advanced from novices may allow for examination of effects of resistance training on the net impulse characteristics.

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## CHAPTER 6

### SUMMARY AND FUTURE INVESTIGATIONS

The purpose of this dissertation was to explore the potential use of net impulse and its characteristics in vertical jumping to monitor athletes' performance status and responses/adaptations to interventions. The net impulse characteristics were defined as variables related to a vertical jump force-time curve that are considered to have an influence on net impulse values and/or shape if one or more of them is/are altered. These characteristics were net impulse height and width, rate of force development, shape factor, and net impulse proportion. In order to fulfill the purpose, three studies were conducted.

Because this dissertation used a unique approach to calculate net impulse and few studies previously utilized most of the net impulse characteristics, the basic measurement premises of reliability and validity were needed to be addressed first. Thus, the first study investigated 1) test-retest reliability of net impulse calculated with an alternative approach and of net impulse characteristics and 2) criterion validity of net impulse calculated with the alternative approach in comparison to the traditional approach in both the countermovement and static jumps. The first study concluded that 1) most of the net impulse characteristics examined in this study have sufficient test-retest reliability to be used in both cross-sectional and intervention-based studies. 2) However, rate of force development particularly of the countermovement jump requires a large magnitude of change to overcome the variable's inherent variability. 3) Shape factor and net impulse proportion of the static jump should be used with caution due to relatively low consistency in a rank-order relationship for shape factor (intraclass correlation coefficient (95% confidence interval) = 0.71 (0.05-0.91)) and a systematic bias found for net impulse proportion

(a paired-sample t test  $p$  value = 0.03). 4) The alternative approach to calculate net impulse can be used in place of the criterion approach.

Although the first study reported sufficient reliability for most of the net impulse characteristics, the evidence that these characteristics actually contribute to net impulse was still lacking. However, when a dependent and independent variables are derived from the same source (i.e. the same force-time curves), multicollinearity becomes a statistical problem. Thus, an alternative means was taken to examine contributions of the net impulse characteristics to predicting jump height because net impulse in relation to system mass is the determinant of jump height in theory as mentioned above. Therefore, the second study investigated 1) a relative contribution of each net impulse characteristic to predicting jump height in collegiate athletes and 2) how net impulse characteristics differ according to levels of jump height. The second study concluded that 1) relative net impulse height (net impulse height divided by system mass), net impulse width, and shape factor are the characteristics that contribute to predicting jump height of the countermovement jump while all of the five characteristics contribute to predicting jump height of the static jump. 2) Of the net impulse characteristics found to contribute, relative net impulse height can be an indicator of levels of jump height for both jumps and net impulse proportion for the static jump. Furthermore, although speculative, net impulse width and shape factor of the countermovement jump and shape factor of the static jump among others may be indicators of other factors that may not necessarily be reflected in jump height because they did not statistically show associations with levels of jump height.

The second study showed some evidence that some of the net impulse characteristics have associations with levels of jump height. However, it was based on cross-sectional examination and longitudinal evidence that changes in the net impulse characteristics are related

to an increase in jump height was still lacking. Furthermore, relationships between changes in the net impulse characteristics and force production ability (e.g. strength) are unclear. Thus, the third study investigated 1) how the net impulse characteristics change when jump height increases and 2) how changes in force production ability are related to changes in the net impulse characteristics. The third study concluded that 1) a mechanism of an increase in the countermovement jump height may be to increase the displacement of the countermovement as a result of the increased time-dependent force production ability due to training. Increases in the displacement and kinetics of the countermovement in turn appear to offset an increase in net impulse height while increasing net impulse width and decreasing shape factor. 2) An increase in net impulse proportion is a mechanism to increase static jump height. However, a lack of a statistical correlation between changes in net impulse proportion and in static jump height makes it difficult to suggest mechanistic relationships between changes in the two. There were no statistically significant correlations found between changes in the static jump net impulse characteristics and in force production ability.

In summary, net impulse height and width and shape factor are the net impulse characteristics that contribute to countermovement jump height and thus theoretically to net impulse. Net impulse height and width, rate of force development, shape factor, and net impulse proportion are the characteristics that contribute to static jump height. Relative net impulse height is more important to achieve a higher countermovement jump height than the others while relative net impulse height and net impulse proportion are both important to achieve a higher static jump height. However, an increase in jump height can be achieved without changes in relative net impulse height. For the countermovement jump, increases in net impulse width and shape factor were observed with an increase in jump height. The increases in net impulse width

and shape factor are likely to indicate increases in the displacement and kinetics of the countermovement and in the ability to decelerate quickly to transition to the propulsion phase. These changes are influenced by changes in force production ability that is rather time-dependent. That is, changes in force production ability over and somewhat beyond the duration of countermovement jump net impulse width appear to be more related to changes in jump performance (e.g. take-off velocity) than a change in the maximum force production ability. For the static jump, an increase in net impulse proportion was observed with an increase in jump height. This is in line with the finding of the second study. However, a lack of statistically significant correlations between changes in the net impulse characteristics and in the isometric kinetic variables makes it impossible to associate the observed changes.

The findings of this dissertation show the possibility of the use of the net impulse characteristics to monitor athletes' performance status and responses/adaptations to interventions. However, because this dissertation was the first to explore the potential use of the net impulse characteristics athletes' performance monitoring, there are still many topics to be studied before practical recommendations are made. These include but are not limited to relationships with other performance measures, effects of specific training protocols, acute interventions, fatigue, and over-reaching and tapering. Potential performance measures include maximum strength, sprint, and change of direction. Training protocols of interest may be traditional strength training, power training, and plyometric training. Post-activation potentiation and whole body vibration are good examples of acute interventions. Effects of fatigue can be examined in terms of acute and accumulated fatigue of different origins (e.g. metabolic/muscular vs. neural). Effects of over-reaching and tapering can be examined in relation to actual sport performance of interest along with other physiological measures such as a testosterone-to-cortisol ratio. Last, in designing

studies to examine these topics, it is important to recognize that the degree of control used in studies should not compromise athletes' performance as well as what they would actually do in order to retain ecological validity and thus external validity.



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## APPENDICES

### Appendix A: ETSU Institutional Review Board Approval



East Tennessee State University  
Office for the Protection of Human Research Subjects • Box 70565 • Johnson City, Tennessee 37614-1707  
Phone: (423) 439-6053 Fax: (423) 439-6060

#### IRB APPROVAL – Continuing Expedited Review

January 17, 2012

Dr. Michael Stone  
KLSS  
Box 70654

Re: Relationship Between Descent Depth and Jump Height  
IRB#: c0510.14s

The following items were reviewed and approved by an expedited process:

- Form 107 (no conflict identified); Previously approved Narrative; Informed Consent (ver. 5/21/10 stamped approved 01/17/12); Video Release (ver. 5/21/10 stamped approved 01/17/12); Protocol History

On January 17, 2012, a final approval was granted for a period not to exceed 12 months and will expire on January 16, 2013. The expedited approval of the study will be reported to the convened board on the next agenda.

The following **enclosed stamped, approved ICD** has been stamped with the approval and expiration date and this document must be copied and provided to each participant prior to participant enrollment:

- Informed Consent Document (ver. 5/21/10 stamped approved 1/17/12)
- Video Release (ver. 5/21/10 stamped approved 1/17/12)

Federal regulations require that the original copy of the participant's consent be maintained in the principal investigator's files and that a copy is given to the subject at the time of consent.

Unanticipated Problems Involving Risks to Subjects or Others must be reported to the IRB (and VA R&D if applicable) within 10 working days.

Proposed changes in approved research cannot be initiated without IRB review and approval. The only exception to this rule is that a change can be made prior to IRB approval when necessary to eliminate apparent immediate hazards to the research subjects [21 CFR 56.108 (a)(4)]. In such a



Accredited Since December 2005

case, the IRB must be promptly informed of the change following its implementation (within 10 working days) on Form 109 ([www.etsu.edu/irb](http://www.etsu.edu/irb)). The IRB will review the change to determine that it is consistent with ensuring the subject's continued welfare.

Sincerely,  
Dale Schmitt, Ph.D., Vice-Chair  
ETSU Campus IRB



East Tennessee State University  
Office for the Protection of Human Research Subjects • Box 70565 • Johnson City, Tennessee 37614-1707  
Phone: (423) 439-6053 Fax: (423) 439-6060

### IRB APPROVAL – Continuing Expedited Review

August 16, 2011

Dr. Michael Stone  
KLSS  
Box 70654

Re: Long Term Athlete Monitoring  
IRB#: c06-033s

The following items were reviewed and approved by an expedited process:

- Form 107 (no conflict identified); Previously approved Narrative; Informed Consent Document for Athletes Ages 18 Years of Age and Older (ver. 08/20/08 stamped approved 08/15/11); Assent Document for Athletes Ages Under 18 Years of Age (ver. 10/27/08 stamped approved 08/15/11); Video Recording Release consent Form (ver. 01/25/10 stamped approved 08/15/11); Parental Permission Form (ver. 10/24/07 stamped approved 08/15/11); Previous child determinations; Minor modifications approved during continuing review period

On **August 15, 2011**, a final approval was granted for a period not to exceed 12 months and will expire on **August 14, 2012**. The expedited approval of the study will be reported to the convened board on the next agenda.

The following **enclosed stamped, approved ICD** has been stamped with the approval and expiration date and this document must be copied and provided to each participant prior to participant enrollment:

- Informed Consent Document for Athletes Ages 18 Years of Age and Older (ver. 08/20/08 stamped approved 08/15/11)
- Assent Document for Athletes Ages Under 18 Years of Age (ver. 10/27/08 stamped approved 08/15/11)
- Video Recording Release consent Form (ver. 01/25/10 stamped approved 08/15/11)
- Parental Permission Form (ver. 10/24/07 stamped approved 08/15/11)

Federal regulations require that the original copy of the participant's consent be maintained in the principal investigator's files and that a copy is given to the subject at the time of consent.



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The Vice-Chair concurred with the previous child determinations: (1) the research is not greater than minimal risk to children because permission from parent and assent from children will be obtained. The IRB determined that the permission of one parent is sufficient in the event that only one parent is available. Permission will be obtained and documented appropriately. If permission is to be obtained from a guardian, the guardian will be an individual who is authorized under applicable State and local law to consent on behalf of the child to general medical care. The IRB determined that assent is required for each child who is capable of providing assent based on age, maturity, and psychological state. All are considered capable of providing assent as they are ETSU students participating in intercollegiate sports. The IRB determined that assent must be documented by child signature on assent form.

Unanticipated Problems Involving Risks to Subjects or Others must be reported to the IRB (and VA R&D if applicable) within 10 working days.

Proposed changes in approved research cannot be initiated without IRB review and approval. The only exception to this rule is that a change can be made prior to IRB approval when necessary to eliminate apparent immediate hazards to the research subjects [21 CFR 56.108 (a)(4)]. In such a case, the IRB must be promptly informed of the change following its implementation (within 10 working days) on Form 109 ([www.etsu.edu/irb](http://www.etsu.edu/irb)). The IRB will review the change to determine that it is consistent with ensuring the subject's continued welfare.

Sincerely,  
Dale Schmitt, Ph.D., Vice-Chair  
ETSU Campus IRB





East Tennessee State University  
Office for the Protection of Human Research Subjects • Box 70565 • Johnson City, Tennessee 37614-1707  
Phone: (423) 439-6053 Fax: (423) 439-6060

### IRB APPROVAL – Continuing Expedited Review

December 21, 2011

Dr. Michael Stone  
KLSS  
Box 70654

Re: Long-term non-ETSU Athlete Monitoring  
IRB#: c0910.10s

The following items were reviewed and approved by an expedited process:

- Form 107 (no conflict identified); Video Release (ver 01/25/10 stamped approved 12/19/11); ICD for athletes ages 18 and older (ver. 12/10/10 stamped approved 12/19/11); Assent for athletes under 18 (ver. 12/10/10 stamped approved 12/19/11); Parental Permission Form (ver. 12/10/10 stamped approved 12/19/11); Previously approved Narrative; Previously approved Consent/Assent documents; Previous Child determinations; Protocol History

On **December 19, 2011**, a final approval was granted for a period not to exceed 12 months and will expire on **December 18, 2012**. The expedited approval of the study will be reported to the convened board on the next agenda.

The following **enclosed stamped, approved ICD** has been stamped with the approval and expiration date and this document must be copied and provided to each participant prior to participant enrollment:

- Assent (ver. 12/10/10 stamped approved 12/19/11)
- ICD 18+ (ver. 12/10/10 stamped approved 12/19/11)
- Parental Permission (ver. 12/10/10 stamped approved 12/19/11)
- Video Release (ver. 01/25/10 stamped approved 12/19/11)

Federal regulations require that the original copy of the participant's consent be maintained in the principal investigator's files and that a copy is given to the subject at the time of consent.

The IRB Vice-Chair concurred with the previous child determinations as follows: Based on the review of the Children's Advocate, the IRB determined that no greater than minimal risk to children is presented because as stated in the narrative all participants will participate in a normal series of



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exercises that present minimal risk. The IRB determined that the permission of each child's parents or guardian will be obtained unless one parent is deceased, unknown, incompetent, or not reasonably available, or when only one parent has legal responsibility for the care and custody of the child. Sufficient and adequate provisions are in place for permission to be obtained appropriately and to be documented. If permission is to be obtained from a guardian, the guardian will be an individual who is authorized under applicable State or local law to consent on behalf of the child to general medical care. The IRB determined that assent is a requirement for each child who is capable of providing assent based on age maturity, and psychological state and as such assent must be obtained from all students by their signature on the assent form.

Unanticipated Problems Involving Risks to Subjects or Others must be reported to the IRB (and VA R&D if applicable) within 10 working days.

Proposed changes in approved research cannot be initiated without IRB review and approval. The only exception to this rule is that a change can be made prior to IRB approval when necessary to eliminate apparent immediate hazards to the research subjects [21 CFR 56.108 (a)(4)]. In such a case, the IRB must be promptly informed of the change following its implementation (within 10 working days) on Form 109 ([www.etsu.edu/irb](http://www.etsu.edu/irb)). The IRB will review the change to determine that it is consistent with ensuring the subject's continued welfare.

Sincerely,  
Dale Schmitt, Ph.D., Vice-Chair  
ETSU Campus IRB

## Appendix B: Informed Consent Documentation

PRINCIPAL INVESTIGATOR: Dr. Michael H. Stone

TITLE OF PROJECT: The relationship between the descent depth and jump height

**EAST TENNESSEE STATE UNIVERSITY  
VETERANS AFFAIRS MEDICAL CENTER  
INSTITUTIONAL REVIEW BOARD  
GUIDELINES FOR DEVELOPING AN INFORMED CONSENT DOCUMENT (ICD)  
FOR PROSPECTIVE RESEARCH INTENDED FOR REVIEW**

### INTRODUCTION

This Informed Consent will explain about being a participant in a research study. It is important that you read this material carefully and then decide if you wish to be a volunteer.

### PURPOSE:

The purpose(s) of this research study is/are as follows:

To examine the relationship between the descent depth and jump height. The secondary purpose of the study is to determine the relationship between impulse generated during the ascending phase of jump and jump height. The resulting knowledge is likely to contribute to the understanding of the relationship between impulse generated and jump height. In addition, the knowledge is likely to contribute to enhancing jump performance.

### DURATION:

The data collection for this study consists of a single session, which is expected to last 30 to 45 minutes depending on how many jumps you might be performing. The number of jumps that you might perform depends on how proficiently you can perform static jumps (see PROCEDURES for the detailed description of static jumps).

### PROCEDURES:

The procedures, which will involve you as a research subject, include:

- 1) Body mass and height measurement: your body mass will be measured using a digital scale. Your standing height and seated height will be measured using a stadiometer and a tape on a wall with ruler lines drawn on it, respectively.
- 2) Warm-up: you will perform a standard warm-up protocol used in our laboratory before a series of jumps. The standard warm-up protocol consists of 15 jumping jacks, 1 set of 5 mid-thigh pulls\* with a weightlifting bar that weighs 20kg, and 3 sets of 5 mid-thigh pulls with a weightlifting bar that weighs 40kg for females and 60 kg for males. \*Mid-thigh pull is an exercise derived from Weightlifting, where you repeat a jump-like extension of the hip, knee, and ankle joint from about 130 degree knee angle with shrugging while holding a weightlifting bar in front at the mid-thigh level.

**APPROVED**  
By the ETSU IRB

DOCUMENT VERSION EXPIRES

JAN 17 2012

JAN 16 2013

Ver. 5/21/2010

By   
Cheryl R. B. Coordinator

Page 1 of 5

ETSU IRB

Subject Initials \_\_\_\_\_

PRINCIPAL INVESTIGATOR: Dr. Michael H. Stone

TITLE OF PROJECT: The relationship between the descent depth and jump height

- 3) Jump testing session: you will be asked to perform 6 different types of jumps while holding a weightless PVC pipe across the back of the shoulders – countermovement jumps (regular jump) from your preferred depth and static jumps\* from the depth you selected in countermovement jump, 120 degree knee angle, 105 degree knee angle, 90 degree knee angle, and 75 degree knee angle. \*Static jump is a type of jump, where your movement is paused for a few seconds after descending and before ascending for take-off. For each jump type, you will be asked to jump at least 2 times. However, the performance of these 2 jumps must meet the criteria necessary for this study. These criteria are providing maximum effort and initiating the ascending phase of static jump without any countermovement.

In addition, the procedures may be terminated by the investigator if we observe signs and symptoms of abnormal health conditions and/or physical injuries. You may also terminate the test at any time.

ALTERNATIVE PROCEDURES/TREATMENTS

There are no alternative procedures/treatments available if you elect not to participate in this study.

POSSIBLE RISKS/DISCOMFORTS

The possible risks and/or discomforts of your involvement include:

Risks involved in this study are very minimal but muscle strain and joint sprain might be possible. You might also experience muscle soreness 24 to 48 hours after the data collection. You should not participate in this study if you are pregnant.

Your physical activities must also be controlled outside this study. You should not perform any strenuous, vigorous, and fatiguing exercise or activities starting 48 hours prior to your data collection session. These physical activities include, but are not limited to, intense and/or long-lasting resistance training, running, swimming, and cycling. These also include participating in a full-length team sport game such as basketball, soccer, and football and/or participating in multiple pick-up games such as basketball. However, this does not mean that you can not perform daily living activities or light exercise.

**APPROVED**  
By the ETSU IRB

DOCUMENT VERSION EXPIRES

Ver. 5/21/2010

JAN 17 2012

Page 2 of 5

JAN 16 2013

Subject Initials \_\_\_\_\_

By   
Chair/IRB Coordinator

ETSU IRB

PRINCIPAL INVESTIGATOR: Dr. Michael H. Stone

TITLE OF PROJECT: The relationship between the descent depth and jump height

POSSIBLE BENEFITS

The possible benefits of your participation:

- 1) Measurement of jump height with high accuracy
- 2) Finding the optimum descent depth for jumps. This can be beneficial information if they participate in sports which involve jumping movement.

COMPENSATION FOR MEDICAL TREATMENT:

East Tennessee State University (ETSU) will pay the cost of emergency first aid for any injury that may happen as a result of your being in this study. ETSU makes no commitment to pay for any other medical treatment. Claims against ETSU or any of its agents or employees may be submitted to the Tennessee Claims Commission. These claims will be settled to the extent allowable as provided under TCA Section 9-8-307. For more information about claims call the Chairman of the Institutional Review Board of ETSU at 423/439-6055.

**Statement for MSHA studies:**

If taking part in this research injures you, you will be given emergency treatment. You may or may not be responsible to pay for this emergency treatment. There is no promise to pay for such emergency treatment by anyone. In the end, the decision as to who shall pay for your emergency treatment will depend on the facts, the reason for the injury and state law.

FINANCIAL COSTS

There are no additional costs to participants that may result from participation in the research.

VOLUNTARY PARTICIPATION

Participation in this research experiment is voluntary. You may refuse to participate. You can quit at any time. If you quit or refuse to participate, the benefits or treatment to which you are otherwise entitled will not be affected. You may quit by calling Dr. Michael H. Stone, whose phone number is 423-439-5796. You will be told immediately if any of the results of the study should reasonably be expected to make you change your mind about staying in the study.

In addition, if significant new findings during the course of the research which may relate to the participant's willingness to continue participation are likely, the consent process must disclose that significant new findings developed during the course of the

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JAN 17 2012

By [Signature]

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JAN 16 2013

PRINCIPAL INVESTIGATOR: Dr. Michael H. Stone

TITLE OF PROJECT: The relationship between the descent depth and lump height

research which may relate to the participant's willingness to continue participation will be provided to the participant.

In addition, if there might be adverse consequences (physical, social, economic, legal, or psychological) of a participant's decision to withdraw from the research, the consent process must disclose those consequences **and** procedures for orderly termination of participation by the participant.

CONTACT FOR QUESTIONS

If you have any questions, problems or research-related medical problems at any time, you may call Satoshi Mizuguchi at 423-439-4655, or Dr. Michael H. Stone at 423-439-5796. You may call the Chairman of the Institutional Review Board at 423/439-6054 for any questions you may have about your rights as a research subject. If you have any questions or concerns about the research and want to talk to someone Independent of the research team or you can't reach the study staff, you may call an IRB Coordinator at 423/439-6055 or 423/439/6002.

CONFIDENTIALITY

Every attempt will be made to see that your study results are kept confidential. A copy of the records from this study will be stored in a file cabinet located in an office of Sport and Exercise Sciences Laboratory for at least 5 years after the end of this research. The results of this study may be published and/or presented at meetings without naming you as a subject. Although your rights and privacy will be maintained, the Secretary of the Department of Health and Human Services, ETSU IRB, and personnel particular to this research (Dr. Michael W. Ramsey) have access to the study records. Your records will be kept completely confidential according to current legal requirements. They will not be revealed unless required by law, or as noted above.

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PRINCIPAL INVESTIGATOR: Dr. Michael H. Stone

TITLE OF PROJECT: The relationship between the descent depth and jump height

By signing below, you confirm that you have read or had this document read to you. You will be given a signed copy of this informed consent document. You have been given the chance to ask questions and to discuss your participation with the investigator. You freely and voluntarily choose to be in this research project.

_____ SIGNATURE OF PARTICIPANT	_____ DATE
_____ PRINTED NAME OF PARTICIPANT	_____ DATE
_____ SIGNATURE OF INVESTIGATOR	_____ DATE
_____ SIGNATURE OF WITNESS (if applicable)	_____ DATE

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JAN 16 2013

**Research Project Title:** Relationship Between Descent Depth and Jump Height

Video Recording Release Consent Form

Instructions: Video or photographic recordings may be made of you while participating in aspects of this research project (e.g. training, competition, laboratory). The Investigator would like your permission to use your video image for purposes outside of the study. Please use this form to indicate whether you are willing to allow the use of your Image for the purposes described below. Your name will not be associated with the image in any case. You may request to stop the photography or video-taping or erase any portion of the tape at any time.

- |  | Yes                      | No                       |
|--|--------------------------|--------------------------|
| 1. The video-tapes/photo can be shown to other athletes participating in similar projects. | <input type="checkbox"/> | <input type="checkbox"/> |
| 2. The video-tapes/photo can be used for scientific publications and/or presentations.     | <input type="checkbox"/> | <input type="checkbox"/> |
| 3. The video-tapes/photo can be shown in non-scientific publications and/or presentations. | <input type="checkbox"/> | <input type="checkbox"/> |
| 4. The video-tapes/photo can be shown in classrooms to students.                           | <input type="checkbox"/> | <input type="checkbox"/> |

Your Signature indicates that you have read the information and made a decision about how your video image may be used.

Signature: \_\_\_\_\_

Print: \_\_\_\_\_

Date: \_\_\_\_\_

Project: The effects of two different squat depths on metabolic responses to Back Squat exercise

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**Informed Consent Document for Athletes Ages 18 Years of Age and Older**

**Principle Investigator:** Michael H. Stone

**Title of Project:** Long-term Monitoring of Athletes

**Introduction:**

This informed consent will explain about being a participant in a research project. It is important that you read this material carefully and then decide if you wish to be a participant.

**Purpose:** Appropriate monitoring is an important component to a comprehensive training and competition program. The tests that will be performed on a regular basis have been planned out with your coach. These tests will enable your coach to better prescribe a training program that will have a greater potential to enhance your performance. **The purpose of this informed consent is not to determine your participation in the monitoring process – rather it is to determine whether we can use your data in scientific study (including presentations and publications).**

**Duration:**

Testing will be carried out in regular intervals (as planned with your coach) over the period of time that you are a competitive athlete in the Intercollegiate Athletic Department at ETSU.

**Procedures:**

These procedures are already being performed as part of an athlete monitoring program and can include:

1. hydration status measured by refractometry (urinary specific gravity)
2. body composition (skinfolds, plethysmography, bioelectrical impedance)
3. test of strength characteristics including isometric and dynamic measures of force, rate of force development, impulse, and power output. (force plates, potentiometers, cycle ergometers etc.)
4. measures of speed and acceleration (timing gates)
5. measures of agility (timing gates)
6. measures of anaerobic capacity and high-intensity exercise endurance (Wingate cycle tests etc.)

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**Principle Investigator:** Michael H. Stone

**Title of Project:** Long-term Athlete Monitoring

**Procedures con't:**

7. measures of aerobic capacity and low-intensity exercise endurance (treadmill and cycle tests, beep test etc.)
8. HR, blood pressure measures
9. when appropriate - measures of specific blood borne parameters (e.g. testosterone, cortisol etc.) - carried out with appropriate medical supervision
10. when appropriate - questionnaires will be administered dealing with recovery from training such as RestQ, profile of modes state (POMS) (fatigue management), recovery from trauma (e.g. concussion).

**Alternative Procedures**

There are no alternative procedures except not to participate

**POSSIBLE RISKS/DISCOMFORTS:**

The only risk to the athletes in regards to this study is a loss of confidentiality. The risks are explained to the athletes prior to the initiation of the monitoring procedures. The procedures are already performed as part of an athlete monitoring process and the potential for injury is small - all participants will be performing exercises regularly executed in training. For example: There is a potential for a sprain (such as the ankle) upon landing from the vertical jump (it should be noted that the injury potential of the vertical jump is quite low compared to the inherent injury potential of most training routines) - there are no anticipated injuries as result of using these protocols. If blood is drawn during the test period - there is a slight potential for bruising or infection.

**POSSIBLE BENEFITS:**

Superior sports performance depends upon the process of recovery-adaptation, (i.e. the training stimulus results in an adaptation during the recovery phase). Thus adequate monitoring of the recovery -adaptation process can enhance the potential for superior performance. Monitoring allows the sports enhancement team (e.g. coaches, sports physiologists and biomechanics, sports medical personnel and sports psychologists) to appropriately adjust the training load.

**Financial Costs**

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There are no financial costs to you.

**Principle Investigator:** Michael H. Stone

**Title of Project:** Long-term Monitoring of Athletes

**Compensation in Form of payment to Research Participants**

There is no compensation for your participation in this research

**VOLUNTARY PARTICIPATION:**

Participation in the research portion of this program is voluntary. You may refuse to participate or withdraw from the study at any time. If you refuse or quit, the benefits or treatments to which you may be entitled to will not be affected. You can withdraw by calling Dr. Michael H. Stone whose phone number is 423-439-5796, or Dr. Michael Ramsey, 423-439-4375.

**CONTACT FOR QUESTIONS:**

If you have any questions, problems or research-related problems at any time, you may call Michael Stone at 423-439-5796 or Michael Ramsey at 423-439-4375. You may call the chairman of the Institutional Review Board at 423-439-6054 for any questions you have about your rights as a research subject. If you have any questions or concerns about the research and want to talk to someone independent of the research team or you can't reach the study staff, you may call an IRB coordinator at 423-439-6055 or 423-439-6002.


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ETSU IRB

Subject Initials \_\_\_\_\_

**Principle Investigator:** Michael H. Stone

**Title of Project:** Long-term Monitoring of Athletes

**CONFIDENTIALITY:**

Every attempt will be made to see that your study results are kept confidential. A copy of the records from this study will be stored in the Exercise and Sports Science Laboratory for at least 10 years after the end of the research. The results of this on-going study will be published and/or presented at meetings without naming you as an athlete involved in this study. Although your rights and privacy will be maintained, the secretary of the Department of Health and Human Services, the ETSU IRB and the staff involved in the research have access to the study records. Since videotaping is being performed there is a possible loss of confidentiality.

After a testing period, a summary of the study results with group averages and your individual scores will be returned to you and your coach as soon as possible after analyses of the data are finished.

By signing below, you confirm that you have read this document or had it read to you. You will be given a signed copy of this informed consent document.

---

Signature of Participant	Date
Signature of Investigator	Date

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**Assent Document for Athletes Ages Under 18 Years of Age**

**Principle Investigator:** Michael H. Stone

**Title of Project:** Long-term Monitoring of Athletes

***Introduction:***

This informed consent will explain about being a participant in a research project. It is important that you read this material carefully and then decide if you wish to be a participant.

**Purpose:** Appropriate monitoring is an important component to a comprehensive training and competition program. The tests that will be performed on a regular basis have been planned out with your coach. These tests will enable your coach to better prescribe a training program that will have a greater potential to enhance your performance. **The purpose of this informed consent is not to determine your participation in the monitoring process – rather it is to determine whether we can use your data in scientific study (including presentations and publications).**

**Duration:**

Testing will be carried out in regular intervals (as planned with your coach) over the period of time that you are a competitive athlete in the Intercollegiate Athletic Department at ETSU.

**Procedures:**

These procedures are already being performed as part of an athlete monitoring program and can include:

1. hydration status measured by refractometry (urinary specific gravity)
2. body composition (skinfolds, plethysmography, bioelectrical impedance)
3. test of strength characteristics including isometric and dynamic measures of force, rate of force development, impulse, and power output. (force plates, potentiometers, cycle ergometers etc.)
4. measures of speed and acceleration (timing gates)
5. measures of agility (timing gates)
6. measures of anaerobic capacity and high-intensity exercise endurance (Wingate cycle tests etc.)

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By   
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**Principle Investigator:** Michael H. Stone

**Title of Project:** Long-term Athlete Monitoring

**Procedures con't:**

- 7. measures of aerobic capacity and low-intensity exercise endurance (treadmill and cycle tests, beep test etc.)
- 8. HR, blood pressure measures
- 9. when appropriate - measures of specific blood borne parameters (e.g. testosterone, cortisol etc.) - carried out with appropriate medical supervision
- 10. when appropriate - questionnaires will be administered dealing with recovery from training such as RestQ, profile of modes state (POMS) (fatigue management), recovery from trauma (e.g. concussion).

**Alternative Procedures**

There are no alternative procedures except not to participate.

**POSSIBLE RISKS/DISCOMFORTS:**

The only risk to the athletes in regards to this study is a loss of confidentiality. The risks are explained to the athletes prior to the initiation of the monitoring procedures. The procedures are already performed as part of an athlete monitoring process and the potential for injury is small - all participants will be performing exercises regularly executed in training. For example: There is a potential for a sprain (such as the ankle) upon landing from the vertical jump (it should be noted that the injury potential of the vertical jump is quite low compared to the inherent injury potential of most training routines) - there are no anticipated injuries as result of using these protocols If blood is drawn during the test period - there is a slight potential for bruising or infection.

**POSSIBLE BENEFITS:**

Superior sports performance depends upon the process of recovery-adaptation, (i.e. the training stimulus results in an adaptation during the recovery phase). Thus adequate monitoring of the recovery -adaptation process can enhance the potential for superior performance. Monitoring allows the sports enhancement team (e.g. coaches, sports physiologists and biomechanics, sports medical personnel and sports psychologists) to appropriately adjust the training load.

**Financial Costs**

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By the ETSU IRB

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By *RB*  
Chair/IRB Coordinator

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There are no financial costs to you.

**Principle Investigator:** Michael H. Stone

**Title of Project:** Long-term Monitoring of Athletes

**Compensation in Form of payment to Research Participants**

There is no compensation for your participation in this research

**VOLUNTARY PARTICIPATION:**

Participation in the research portion of this program is voluntary. You may refuse to participate or withdraw from the study at any time. If you refuse or quit, the benefits or treatments to which you may be entitled to will not be affected. You can withdraw by calling Dr. Michael H. Stone whose phone number is 423-439-5796, or Dr. Michael Ramsey, 423-439-4375

**CONTACT FOR QUESTIONS:**

If you have any questions, problems or research-related problems at any time, you may call Michael Stone at 423-439-5796 or Michael Ramsey at 423-439-4375. You may call the chairman of the Institutional Review Board at 423-439-6054 for any questions you have about your rights as a research subject. If you have any questions or concerns about the research and want to talk to someone independent of the research team or you can't reach the study staff, you may call an IRB coordinator at 423-439-6055 or 423-439-6002.

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**Principle Investigator:** Michael H. Stone

**Title of Project:** Long-term Monitoring of Athletes

**CONFIDENTIALITY:**

Every attempt will be made to see that your study results are kept confidential. A copy of the records from this study will be stored in the Exercise and Sports Science Laboratory for at least 10 years after the end of the research. The results of this on-going study will be published and/or presented at meetings without naming you as an athlete involved in this study. Although your rights and privacy will be maintained, the secretary of the Department of Health and Human Services, the ETSU IRB and the staff involved in the research have access to the study records. Since videotaping is being performed there is a possible loss of confidentiality.

After a testing period, a summary of the study results with group averages and your individual scores will be returned to you and your coach after as soon as possible after analyses of the data are finished.

By signing below, you confirm that you have read this document or had it read to you. You will be given a signed copy of this informed consent document.

---

Signature of Participant

Date

---

Signature of Investigator

Date

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Chair/IRB Coordinator



**Parental Permission Form**

**Principle Investigator:** Michael H. Stone

**Title of Project:** Long-term Monitoring of Athletes

**Introduction:**

This informed consent will explain about your child being a participant in a research. It is important that you read this material carefully and then decide if you wish that your child be a participant.

**Purpose:** Appropriate monitoring is an important component to a comprehensive training and competition program. The tests that will be performed on a regular basis have been planned out with your child's coach. These tests will enable your child's coach to better prescribe a training program that will have a greater potential to enhance your performance. **The purpose of this informed consent is not to determine your child's participation in the monitoring process – rather it is to determine whether we can use your child's data in scientific study (including presentations and publications).**

**Duration:**

Testing will be carried out in regular intervals (as planned with your child's coach) over the period of time that your child is a competitive athlete in the Intercollegiate Athletic Department at ETSU.

**Procedures:**

The procedures used depend upon the specific needs of the study and can include:

1. hydration status measured by refractometry (urinary specific gravity)
2. body composition (skinfolds, plethysmography, bioelectrical impedance)
3. test of strength characteristics including isometric and dynamic measures of force, rate of force development, impulse, and power output. (force plates, potentiometers, cycle ergometers etc.)
4. measures of speed and acceleration (timing gates)
5. measures of agility (timing gates)
6. measures of anaerobic capacity and high-intensity exercise endurance (Wingate cycle tests etc.)

**Principle Investigator:** Michael H. Stone

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**Title of Project:** Long-term Athlete Monitoring

**Procedures con't:**

- 7. measures of aerobic capacity and low-intensity exercise endurance (treadmill and cycle tests, beep test etc.)
- 8. HR, blood pressure measures
- 9. when appropriate - measures of specific blood borne parameters (e.g. testosterone, cortisol etc.) - carried out with appropriate medical supervision
- 10. when appropriate - questionnaires will be administered dealing with recovery from training such as RestQ, profile of modes state (POMS) (fatigue management), recovery from trauma (e.g. concussion).

The portion of this protocol will be the collection and publication of the data already being collected from the procedures already being performed

**Alternative Procedures**

There are no alternative procedures except not have your child participate

**POSSIBLE RISKS/DISCOMFORTS:**

The only risk to the athletes in regards to this study is a loss of confidentiality. The risks are explained to the athletes prior to the initiation of the monitoring procedures. The procedures are already performed as part of an athlete monitoring process and the potential for injury is small - all participants will be performing exercises regularly executed in training. For example: There is a potential for a sprain (such as the ankle) upon landing from the vertical jump (it should be noted that the injury potential of the vertical jump is quite low compared to the inherent injury potential of most training routines) - there are no anticipated injuries as result of using these protocols If blood is drawn during the test period - there is a slight potential for bruising or infection.

**POSSIBLE BENEFITS:**

Superior sports performance depends upon the process of recovery-adaptation, (i.e. the training stimulus results in an adaptation during the recovery phase). Thus adequate monitoring of the recovery -adaptation process can enhance the potential for superior performance. Monitoring allows the sports enhancement team (e.g. coaches, sports physiologists and biomechanics, sports medical personnel and sports psychologists) to appropriately adjust the training load.

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By   
Chair/IRB Coordinator

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**Principle Investigator:** Michael H. Stone

**Title of Project:** Long-term Monitoring of Athletes

**Financial Costs**

There are no financial costs to your child.

**Compensation in Form of payment to Research Participants**

There is no compensation for your child to participate in this research

**VOLUNTARY PARTICIPATION:**

Participation in the research portion of this program is voluntary. Your child may refuse to participate or withdraw from the study at any time. If your child refuses or quits, the benefits or treatments to which your child may be entitled to will not be effected. Your child can withdraw by calling Dr. Michael H. Stone whose phone number is 423-439-5796, or Dr. Michael Ramsey, 423-439-4375.

**CONTACT FOR QUESTIONS:**

If you or your child have any questions, problems or research-related problems at any time, you may call Michael Stone at 423-439-5796 or Michael Ramsey at 423-439-4375. You may call the chairman of the Institutional Review Board at 423-439-6054 for any questions you have about your rights as a research subject. If you have any questions or concerns about the research and want to talk to someone independent of the research team or you can't reach the study staff, you may call an IRB coordinator at 423-439-6055 or 423-439-6002.

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
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**Principle Investigator:** Michael H. Stone

**Title of Project:** Long-term Monitoring of Athletes

**CONFIDENTIALITY:**

Every attempt will be made to see that your child's study results are kept confidential. A copy of the records from this study will be stored in the Exercise and Sports Science Laboratory for at least 10 years after the end of the research. The results of this on-going study will be published and/or presented at meetings without naming your child as an athlete involved in this study. Although your child's rights and privacy will be maintained, the secretary of the Department of Health and Human Services, the ETSU IRB and the staff involved in the research have access to the study records. Since videotaping is being performed there is a possible loss of confidentiality.

After a testing period, a summary of the study results with group averages and your child's individual scores will be returned to you child and his/her coach as soon as possible after analyses of the data are finished.


By signing below, you confirm that you have read this document or had it read to you. You will be given a signed copy of this Informed consent document.

---

Signature of Parent or Guardian	Date
Signature of Investigator	Date

Ver. 10/24/07

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Chair/IRB Coordinator

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**Informed Consent Document for Athletes Ages 18 Years of Age and Older**

**Principal Investigator:** Michael H. Stone

**Title of Project:** Long-term Monitoring of non-ETSU Athletes

**Introduction:**

This informed consent will explain about being a participant in a research project. It is important that you read this material carefully and then decide if you wish to be a participant.

**Purpose:** Appropriate monitoring is an important component to a comprehensive training and competition program. The tests that will be performed on a regular basis have been planned out with your coach. These tests will enable your coach to better prescribe a training program that will have a greater potential to enhance your performance. **The purpose of this informed consent is not to determine your participation in the monitoring process – rather it is to determine whether we can use your data for coach education and in scientific study (including presentations and publications).**

**Duration:**

Testing will be carried out in regular intervals (*as planned with your coach*) over the period of time that you are a competitive athlete.

**Procedures:**

These procedures are already being performed as part of an athlete monitoring program and can include:

1. hydration status measured by refractometry (urinary specific gravity)
2. body composition (skinfolds, plethysmography, bioelectrical impedance)
3. test of strength characteristics including isometric and dynamic measures of force, rate of force development, impulse, and power output. (force plates, potentiometers, cycle ergometers etc.)
4. measures of speed and acceleration (timing gates)
5. measures of agility (timing gates)
6. measures of anaerobic capacity and high-intensity exercise endurance (Wingate cycle tests etc.)

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By  
Chair/IRB Coordinator

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Subject Initials \_\_\_\_\_

**Principal Investigator:** Michael H. Stone

**Title of Project:** Long-term non-ETSU Athlete Monitoring

**Procedures con't:**

- 7. measures of aerobic capacity and low-intensity exercise endurance (treadmill and cycle tests, beep test etc.)
- 8. HR, blood pressure measures
- 9. when appropriate - measures of specific blood borne parameters (e.g. testosterone, cortisol etc.) - carried out with appropriate medical supervision
- 10. when appropriate - questionnaires will be administered dealing with recovery from training such as RestQ, profile of modes state (POMS) (fatigue management), recovery from trauma (e.g. concussion).

**Alternative Procedures**

There are no alternative procedures except not to participate

**POSSIBLE RISKS/DISCOMFORTS:**

The only risk to the athletes in regards to this study is a loss of confidentiality. The risks are explained to the athletes prior to the initiation of the monitoring procedures. The procedures are already performed as part of an athlete monitoring process and the potential for injury is small - all participants will be performing exercises regularly executed in training. For example: There is a potential for a sprain (such as the ankle) upon landing from the vertical jump (it should be noted that the injury potential of the vertical jump is quite low compared to the inherent injury potential of most training routines) - there are no anticipated injuries as result of using these protocols If blood is drawn during the test period - there is a slight potential for bruising or infection. Pregnant women will be excluded.

**POSSIBLE BENEFITS:**

Superior sports performance depends upon the process of recovery-adaptation, (i.e. the training stimulus results in an adaptation during the recovery phase). Thus adequate monitoring of the recovery -adaptation process can enhance the potential for superior performance. Monitoring allows the sports enhancement team (e.g. coaches, sports physiologists and biomechanics, sports medical personnel and sports psychologists) to appropriately adjust the training load.

**Financial Costs**

There are no financial costs to you.

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By the ETSU IRB

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By   
Chair/IRB Coordinator

**Principal Investigator:** Michael H. Stone

**Title of Project:** Long-term non-ETSU Athlete Monitoring

**Compensation in Form of payment to Research Participants**

There is no compensation for your participation in this research

**VOLUNTARY PARTICIPATION:**

Participation in the research portion of this program is voluntary. You may refuse to participate or withdraw from the study at any time. If you refuse or quit, the benefits or treatments to which you may be entitled to will not be affected. You can withdraw by calling Dr. Michael H. Stone whose phone number is 423-439-5796, or Dr. Michael Ramsey, 423-439-4375.

**CONTACT FOR QUESTIONS:**

If you have any questions, problems or research-related problems at any time, you may call Michael Stone at 423-439-5796 or Michael Ramsey at 423-439-4375. You may call the chairman of the Institutional Review Board at 423-439-6054 for any questions you have about your rights as a research subject. If you have any questions or concerns about the research and want to talk to someone independent of the research team or you can't reach the study staff, you may call an IRB coordinator at 423-439-6055 or 423-439-6002.

**APPROVED**  
By the ETSU IRB

DEC 19 2011

By   
Chain IRB Coordinator

Ver. 12/10/10

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ETSU IRB

Subject Initials \_\_\_\_\_

**Principal Investigator:** Michael H. Stone

**Title of Project:** Long-term non-ETSU Athlete Monitoring

**CONFIDENTIALITY:**

Every attempt will be made to see that your study results are kept confidential. A copy of the records from this study will be stored in the Exercise and Sports Science Laboratory for at least 10 years after the end of the research. The results of this on-going study will be published and/or presented at meetings without naming you as an athlete involved in this study. Although your rights and privacy will be maintained, the secretary of the Department of Health and Human Services, the ETSU IRB and the staff involved in the research have access to the study records. Since videotaping is being performed there is a possible loss of confidentiality.

After a testing period, a summary of the study results with group averages and your individual scores will be returned to you and your coach as soon as possible after analyses of the data are finished.

By signing below, you confirm that you have read this document or had it read to you. You will be given a signed copy of this informed consent document.

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Signature of Participant	Date
Signature of Investigator	Date


**APPROVED**  
By the ETSU IRB

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ETSU IRB

Subject Initials \_\_\_\_\_



VITA

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Mizuguchi, S.. Dispelling the Myths of Resistance Training  
for Youth. Chapter 13. Strength and Conditioning for  
Young Athletes: Science and Application. Routledge  
Taylor & Francis Group. In press.

Honors and Awards: East Tennessee State University Clemmer College of Education  
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