4-2018

# Effects of Static, Countermovement, and Drop Jump Performance on Power and Rate of Force Development in 6 - 16 Year Old Boys

Lacey E. Jahn
*University of Nebraska-Lincoln*, laceyjahn@me.com

# EFFECTS OF STATIC, COUNTERMOVEMENT, AND DROP JUMP PERFORMANCE ON POWER AND RATE OF FORCE DEVELOPMENT IN 6 - 16 YEAR OLD BOYS

by

Lacey E. Jahn

A THESIS

Presented to the Faculty of

The Graduate College of the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Major: Nutrition and Health Sciences

Under the Supervision of Professor Joel T. Cramer

Lincoln, Nebraska

April, 2018

EFFECTS OF STATIC, COUNTERMOVEMENT, AND DROP JUMP PERFORMANCE ON POWER AND RATE OF FORCE DEVELOPMENT IN 6 - 16 YEAR OLD BOYS

Lacey E. Jahn, M.S.

University of Nebraska, 2018

Advisor: Joel T. Cramer

The purpose of this study was to examine the effects of static, countermovement, and drop jump performance on peak power and peak rate of force development (RFD). The secondary purpose of this study was to examine the relationship between vertical jump outcomes, maturity offset, and muscle cress-sectional area (CSA). During a single testing session, twenty-one young males (mean age ± SD = 12.1 ± 2.4 yrs) performed maximal vertical jumps which included: static jump (SJ), countermovement jump (CMJ), and drop jump from 8 (DJ8), 12 (DJ12) and 16 (DJ16) inches in a randomized order. Peak power increased from SJ to CMJ ($p \leq 0.001$) but showed no subsequent increases among CMJ, DJ8, DJ12, or DJ16. RFD and force showed no increase from SJ to CMJ ($p > 0.05$), an increase from CMJ to DJ8 ($p \leq 0.001$), but no further increases from DJ8 to DJ12 to DJ16 ($p > 0.05$). Eccentric impulse increased systematically from SJ to DJ16 ($p \leq 0.001$). Concentric impulse increased from SJ to CMJ ($p \leq 0.001$), decreased from CMJ to DJ8 ($p = 0.003$), then showed no change from DJ8 to DJ12 to DJ16 ($p > 0.05$). Stepwise regression indicated that the increase in power from SJ to CMJ was best explained by height ($R^2 = 0.517$). These findings suggest CMJ is the optimal jump test for maximizing peak power and concentric work, while minimizing eccentric overload in

male of a similar age to this study. Additionally, growth and development may influence stretch-shortening cycle (SSC) utilization. Future studies are needed to examine the influence of PHV maturity offset and increased muscle CSA on SSC utilization in this model of incremental eccentric pre-loading during vertical jump tests.

# DEDICATION

This thesis is dedicated to my grandparents Carol, Harmon, and Clara for their love and support. I hope to make you proud.

*In Loving Memory*

*Clara B. Jahn*

*February 13, 1930 — June 21, 2016*

*Harmon E. Shoda*

*August 14, 1926 — June 26, 2016*

## ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my advisor, colleagues, family and friends, for which without their encouragement this would have not been possible. To Dr. Joel Cramer for his invaluable mentorship, guidance, and support over the past two years, for his demonstration of confidence in my abilities, and for teaching me more about scientific research than I will ever be able to credit him for here. To the members of my thesis committee, Dr. Koehler and Dr. Takahashi, for having offered direction and helpful feedback. I would like to offer my special thanks to Zachary Gillen and Brianna McKay for their assistance and contributions to this project, as well as to Marnie Shoemaker, Alegra Mendez, and Nick Bohannon, all of whom helped with data collection and provided friendship and good company during late nights in the lab. To my colleagues at Campus Recreation for their unwavering support of my education interests and confidence in my ability to succeed. I am grateful to my parents, Robert and Lisa, for their endless love, support, and sacrifice over the years; for clothing me with confidence and willpower, and for encouraging me to chase my dreams. To my brothers, Jonathan and Adam, for having led by great example and for holding me to the highest standards. To Riley and Liza for their friendship and encouragement. To Daniel for his love, patience, understanding, and support.

TABLE OFCONTENTS

# CHAPTER I: INTRODUCTION

Vertical jump tests are often utilized to evaluate and monitor the development of athletes (2,10,18,21). In adults, vertical jump performance is considered a measurement of vertical power production (2,21,25). Power is often used as an indicator of athletic ability, and vertical jumps have also been examined in youth athletes (10,12,17,18,21). Power output of the lower-body can be measured during or estimated from rapid, maximal-effort exercise (i.e., hopping, jumping, or sprinting) (18). Although lower-body power output related to the vertical jump tests has been well documented in adult populations (4,18,20,23), indirect estimates of lower-body power are typically reported for youth populations by measuring or estimating jump height (10,18). Less is known about the direct assessment of lower-body power in youth athletes by measuring ground reaction forces using more sophisticated techniques (18). Furthermore, even less is understood about the influence of normal growth and development on how eccentric pre-stretching may impact vertical power production during a countermovement vertical jump. Existing evidence in adults suggests that an eccentric pre-load from a countermovement increases power output by 18-30% (6,7,22). Moreover, it has been suggested that emphasizing the eccentric pre-load using a depth jump procedure (1,5,8) may result in even more power output by incrementally engaging the stored elastic energy from the stretch-shortening cycle (SSC).

A vertical jump immediately preceded by a countermovement results in an eccentric pre-load immediately followed by an explosive concentric muscle action (18,21,22). This biomechanical/physiological mechanism of eccentric pre-load (stretch)

immediately followed by a rapid concentric shortening is referred to as the SSC (22). Literature suggests that the elastic energy released during tendon recoil (after the eccentric pre-load) is a plausible explanation for increases in muscle power output during the concentric shortening phase (15,16,22). Since power can be determined as a product of force x velocity, the rapid production of force by skeletal muscles is necessary to increase muscle power output (21,23). Some studies have characterized this by measuring the rate of force development (RFD) (14).

Previous literature has demonstrated increases in power and RFD in adult populations by progressively increasing eccentric pre-load with a countermovement (4,23). However, there is limited research on the direct measurement of force, and thereby power, during vertical jump tests in populations with varying biological maturity (10,18,21). Only recently have studies investigated power output and RFD measured from a force plate to analyze the utilization of the SSC during vertical jumping in youth athletes (12,18,21). Since peak height velocity (PHV) has been used to estimate biological maturity (18,21), it may be useful to examine how eccentric pre-loading and vertical jump performance changes with PHV maturity offset. To our knowledge, SSC performance outcomes have not yet been directly or indirectly compared to muscle cross sectional area (CSA) in youth athletes. Therefore, the primary purpose of this study is to examine power and RFD responses with increases in eccentric pre-loading in young males. The second aim will be to characterize relationships among muscle size, biological maturity, and changes in power with increases in eccentric pre-loading during vertical jump assessments in the same young males.

It is hypothesized that power and RFD will incrementally increase from static to countermovement to rebound drop jumps of increasing depth. Additionally, it is hypothesized that positive correlations will exist among biological maturity, muscle size, and increased power production with incremental eccentric pre-loading.

# CHAPTER II: REVIEW OF LITERATURE

## Asmussen, Bonde-Petersen Study (1974)

Asmussen and Bonde-Petersen investigated the ability of skeletal muscle to absorb and store mechanical energy in the form of elastic energy via maximal static, countermovement, and drop jumps from different heights. Nineteen “young” participants (14 male, 5 female) agreed to participate in this study. Each participant completed 5 maximal jumps: a static jump starting from a semi-squat position, countermovement jump starting from a standing position, and 3 drop jumps starting from 3 different heights. (0.233, 0.404, or 0.60 m). The results showed that jump height increased from the static jump to the countermovement jump to drop jump I (0.233 m) to drop jump II (0.404 m). However, jump height decreased from drop jump II to drop jump III (0.60 m). The authors concluded that as the downward, eccentric phase of the drop jump increased, the amount of stored energy available to engage the elastic contribution of the muscle also increased. The authors further explained that the lack of increase in height from drop jump II to drop jump III may have been due to downward eccentric forces that were too high during the breaking phase of drop jump III. These findings tentatively suggest that there is an upper limit of stored elastic energy within a muscle that can be optimized with drop jump height, after which the height of drop yields diminishing return for power output.

Komi, Bosco Study (1978)

Komi and Bosco examined the influences of different stretch loads on activated leg extensor muscles for maximizing vertical jump performance. Fifty-seven adult males (n = 32) and females (n = 25) agreed to perform maximal vertical jumps on a force platform. Each participant performed jumps from three initial staring positions: squatting position without a countermovement, standing position with a countermovement, and drop jumps from different elevations (20 to 200 cm) resulting in a rebound vertical jump. Participants were instructed to keep their hands on their hips in all test conditions. The results indicated a significant difference in drop height on jumping performance in both males and females. In males, the rise of center of gravity increased with an increase in drop height from 26 to 62 cm. The female participants showed an increase from 20 to 50 cm. The authors concluded that the males were able improve jump performance at higher drop heights than women. The results presented in this study are contrary to Asmussen and Bonde-Petersen (1974), which found a drop height of 41 cm to elicit the best jumping performance. However, these findings may simply suggest that the optimal drop height for maximizing vertical jump power may be proportional to the skeletal muscle mass available to store elastic rebound energy.

Bobbert, Huijing and Van Ingen Schenau Study (1987)

The purpose of this study was to investigate the influence of drop height on the biomechanics of rebound jumping. Six male students (mean age ± SD = 25 ± 4 yrs) completed rebound drop jumps from 20, 40 and 60 cm. The order of the drop heights

were performed randomly. Each participant was barefoot during each maximal effort jump and was instructed to keep their hands on their hips. The results indicated that no significant differences were found in vertical jumping performance between rebound jumps completed from 20, 40, and 60 cm. Previous literature suggested the amount of energy stored in the series elastic component of skeletal muscle increases with the amount of downward, eccentric forces. However, the authors concluded that this hypothesis was not supported by the present study and their findings were in disagreement with the results obtained by Asmussen et al. (74) and Komi et al. (78).

Bobbert, Huijing and Van Ingen Schenau (1987)

Bobbert et al. studied the influence of a drop jumping technique on the biomechanics of jumping. Ten adult male volleyball players (age ± SD = 23 ± 4 yrs) agreed to participate in this study. Three jumping techniques, bounce drop jump (BDJ), counter movement drop jump (CDJ), and counter movement jump (CMJ), were recorded via ground reaction forces, electromyography, and cinematography. Subjects were given 2-3 practice jumps prior to performing each jump trial twice. All three jumping techniques were completed in random order and required the subjects' hands to be placed on the hips. CMJs were performed starting from an upright position on the force platform, a downward movement, and then a consecutive rebound jump as high as possible. During the CDJ, the subjects dropped from 20 cm onto the force plate and gradually reversed the downward movement into an upward movement to jump as high as possible. During the BDJ, subjects also dropped from 20, cm but were instructed to

reverse the downward eccentric movement as quickly as possible after landing on the force platform to jump as high as possible. Results indicated that the power output about the knee and ankle joints were greater during the drop jumps and greatest in the BDJ. A statistically significant difference was found for net power output in the ankles between the CDJ and BDJ (Pmax ± SD = 2,482 ± 945 W and = 4,529 ± 1,917 W, respectively). For net power output, a statistically significant difference was also found in the knees between the CDJ and BDJ (2,796 ± 622 and 3,004 ± 759, respectively). The authors concluded that rebound drop jumps were better suited to improve mechanical power output about the knee and ankle joints.

Jensen and Ebben Study (2007)

Jensen and Ebben investigated plyometric intensity and eccentric rate of force development (RFD) during various plyometric exercises. The plyometric conditions were randomized and included a static jump (SJ), countermovement jump (CMJ), and drop jumps from 46 cm (DJ46) and 61 cm (DJ61). Six Division I male (2) and female (4) athletes (mean age ± SD = 20.3 ± 1.0 yrs) volunteered to participate in this study. Each participant performed at least a three-minute, low intensity, cycling warmup prior to testing. All test conditions were directly recorded using a force platform (OR6-5-2000; Advanced Mechanical Technology, Inc. [AMTI], Water- town, MA). The results indicted a significant difference in the increase of eccentric RFD from the SJ to the CMJ and from CMJ to the DJ61. RFD did not increase from the CMJ to the DJ46. Authors concluded that this indicated variability among plyometric exercises. Authors suggested that landing

technique might influence RFD responses with an increase in plyometric intensity. These results may suggest that increases in RFD during incremental increases in eccentric pre-loading during countermovement and drop jumps may be necessary to optimize the stretch-shortening cycle.

Gerodimos, Zafeiridis, Perks et al. Study (2008)

Gerodimos et al. investigated the effects of utilizing the stretch-shortening cycle (SSC) during countermovement and arm-swing (AS) on vertical jumping performance. One hundred and six male basketball players agreed to perform three different jumps: static jump (SJ), countermovement jump without an arm swing (CMJ), and countermovement jump with an arm swing (CMJA). Participants were divided into one of four groups based on age: young adolescents (14.54 ± 0.41 yrs), old adolescents (16.91 ± 0.27 yrs), and adults (21.88 ± 3.19 yrs). Participants completed a familiarization session prior to experimental trials. During the SJ, participants were instructed to begin from a 90° knee flexion angle and place their hands on their hips. The CMJ began from an upright position followed by a rapid downward movement and extension of the knees while keeping hands on the hips. The CMJA allowed for a backward swing of the arms during the downward movement and then an upward swing during the push-off phase. All jumps were completed on a Bosco Ergojump system (Ergojump, Psion© CM, MAGICA, Rome, Italy). The best performance for each jump was used to analyze the performance of SJ, CMJ, and CMJA. The results indicated that the CMJ performance was significantly higher than SJ. Furthermore, CMJA performance was significantly higher than both CMJ

and SJ across all age groups. Variability in the contribution of SSC and AS was approximately twofold higher in children compared to adults (91 - 146% greater). No significant difference was found in the percent contribution of SSC and AS in vertical jumping across childhood to adulthood. The authors concluded that the significant difference between SJ and CMJ found in pre-pubertal participants may have been due to the method of calculating the effect of SSC and the statistical approach. Gerodimos et al. concluded that the ability to utilize the SSC and AS is not affected by the maturation process of male basketball players.

<u>Lloyd, Oliver, Hughes, et al (2011)</u>

The purpose of this study was to assess pre and post pubescent boys and the influence chronological age has on stretch-shortening cycle performance. Two hundred and fifty young males (age 7-17 years) volunteered to perform a series of static jumps (SJ), countermovement jumps (CMJ), and a maximal hopping test. Subjects were split into ten age groups to compare age related differences in the SJ and CMJ. The SJ began at a 90° knee flexion angle followed by jumping as high as possible. The CMJ began from a standing position, followed by lowering to a self-selected squat depth, and then jumping as high as possible. The maximal hopping test included five repeated maximal vertical hops for analysis of the reactive strength index. Subjects were instructed to jump as high and as quickly as possible. All jumping tests were performed on a mobile contact mat (Smartjump, Fusion Sport, Coopers Plains, Australia). Mean results indicated that no statistically significant differences were found among jump height between SJ and CMJ

from groups G7-G9 (age mean ± SD = 7.86 ± 0.30 to 9.28 ± 0.29). The authors concluded that a pattern of adaptation in the stretch-shortening cycle occurred just before and after the onset of peak height velocity. Researchers also suggested that further research is necessary regarding the potential benefits associated with training for development of the stretch-shortening cycle.

Meylan, Cronin, Oliver, et al. (2012)

The purpose of this study was to investigate the reliability of eccentric and concentric jump kinematics and kinetics in children at different maturity stages according to peak height velocity (PHV) during vertical (VCMJ) and horizontal (HCMJ) countermovement jumps. Forty-two athletic male and female participants ranging 9 to 16 years of age were divided into three maturity groups (Post-PHV, At-PHV, Pre-PHV). Maturity status of all participants was estimated using the equation derived by Mirwald et al. Additionally, to account for the error of measurement in this calculation (± 0.5 years at 95% CI), the Khamis and Roche method was used to also calculate the percentage of adult stature. Prior to testing, each athlete was familiarized with the testing procedure and completed a standardized warm-up. Participants were instructed to eliminate arm swing and jump, horizontally or vertically, as far as possible while landing on two feet on a portable ground reaction force plate (AMTI, ACP, Watertown, MA, USA). The speed and depth of the countermovement was self-selected. The results found that eccentric and concentric peak and mean vertical force and concentric vertical impulse were found to be highly reliable in both jumps across all three groups (CM = 23.6 to 5.5%; CV = 0.7–

9.3%; ICC = 0.83–1.00). Mean and peak concentric power were the only variables to have acceptable reliability in both jumps across all three groups (CM = 27.6 to 3.5%; CV = 6.3–11.6%; ICC = 0.83–0.94). The authors concluded that only eccentric mean power, peak and mean force, and impulse during VCMJ vertical force could be used in children due to the variability found in the other eccentric variables throughout the present study. Meylan et al. suggested that during the familiarization of CMJ's in children, regardless of maturity, an emphasis should be placed on the eccentric phase to increase motor control and to reduce variability. The authors considered vertical concentric peak power and eccentric mean power reliable measures that are indicative of jump and SSC performance in children.

Suchomel, Sands, and McNeal Study (2016)

Suchomel et al. investigated static, countermovement and drop jumps for the upper and lower extremities. Twenty-one USA Junior National Team male gymnasts (mean age ± SD = 15.1 ± 1.7 yrs) agreed to participate in this study. Maximum jump height (MXHT), peak force (PF), rate of force development (RFD), and peak power (PP) were measured during two repetitions of each upper and lower extremity during static, countermovement, and drop jumps. Ground reaction forces for each of these jumps was recorded with a custom-built force platform (61.0 cm x 61.0 cm x 11.2 cm) (Major, Sands, McNeal, Paine, & Kipp, 1998) sampling at 1,000 Hz. Standard national team warm-ups and a self-selected number of practice repetitions of at least two at each testing station were completed prior to all six jump conditions. The upper extremity static jump

position required subjects to start with their hands and chest in contact with the force platform and push up maximally to where the hands rise from the platform. The upper extremity countermovement jump was performed from a standard pushup starting position and then subject rapidly lowered their body and maximally pushed up. The upper extremity drop jump included the hands starting on 30 cm plyometric boxes, dropping to the force platform, and then maximally pushing up. The lower extremity static jump required subjects to jump as high as possible from a below 90° knee angle static position. The lower extremity counter movement jump consisted of a countermovement to a self-selected depth and then jumping as high as possible. The lower extremity drop jump included stepping off a 30 cm plyometric box onto a force platform and immediately jumping as high as possible. Subjects were required to keep their hands on their hips for all lower extremity jumps. One to two minutes of rest were given between each repetition to avoid fatigue. The results indicated that performance was higher in the counter movement jumps compared to the static jumps, while performance was unexpectedly lower in the drop jumps. Statistically significant differences between upper and lower extremities existed among the RFD for static jump to drop jump and countermovement jump to drop jump ($r = 0.79$ and $r = 0.53$, respectively). Upper and lower extremity differences were also found for the relative change in peak force between the static jump and drop jump ($r = 0.53$, respectively). The authors concluded that there was an apparent inability for the young gymnasts to utilize the stretch shortening cycle maximized in a drop jump.

Bosco, Tihanyi, Komi et al. Study (1982)

Bosco et al. investigated the utilization of elastic energy in slow-twitch and fast-twitch skeletal muscle. Ten male (mean age ± SD = 22.9 ± 2.6 years) and four female (17.8 ± 2.1 years) well-trained power athletes performed maximal static and countermovement vertical jumps on a force platform. The static and countermovement jump were completed with large and small angular knee displacement. Movement amplitude was examined by attaching an electrogoniometer to the side of each subject's knee joint. A needle muscle biopsy sample was obtained from the vastus lateralis to determine the skeletal muscle composition of each subject. Actual knee angular displacement was calculated for both large (mean ± SD = 55.3° ± 10.1°) and small (87.3° ± 13.1°) angular knee displacement. The results showed that the average positive force difference between the static and countermovement jumps demonstrated a positive relationship (r = 0.53, respectively) with skeletal muscle fiber composition with small angular displacement of the knee. Instantaneous force developed at the end of the pre-stretch and the percentage of fast-twitch fibers during the small amplitude countermovement jump demonstrated a significant relationship (r = 0.57, respectively). The authors concluded that slow-twitch and fast-twitch muscle fibers benefit differently from the SSC, depending on whether the motion is fast or slow.

Mirwald, Baxter-Jones, Bailey, Beunen (2002)

Mirwald et al. investigated a noninvasive assessment of maturity status in children from anthropometric measures. Data on children between 4 years from Peak Height

Velocity (PHV) and 3 years after PHV were selected for this study. A mixed longitudinal design, 1991 to 1997, was used to assess factors associated with bone mineral accrual in growing adolescents. Two, gender specific, multiple regression equations were calculated from a sample of 152 Canadian children aged 8 to 16 yr (79 boys; 73 girls) to predict PHV. Anthropometric measurements were taken for all subjects and included height, sitting height and body mass. The predictive equation used for males was Maturity Offset = 29.769 + 0.0003007 · Leg Length and Sitting Height interaction - 0.01177 · Age and Leg Length interaction + 0.01639 · Age and Sitting Height interaction + 0.445 · Leg by Height ratio. The results indicated that the coefficient of determination ($R^2$) for the model was 0.92 and the SEE was 0.49, respectively. The mean difference between actual and predicted maturity offset for the verification samples was 0.24 (SD = 0.65) yr.
Authors concluded that the regression equation is reliable for the prediction of age of PHV. Additionally, authors deemed the predictive equation as a practical, noninvasive solution for the measure of biological maturity.

# CHAPTER III: METHODS

## Participants

Twenty-one males (mean age ± SD = 12.1 ± 2.4 yrs) who regularly engage in sporting activities volunteered to participate in the investigation. The present study was approved by the University Institutional Review Board for Human Subjects (IRB# 20171017495EP, Title: *Changes in Noninvasive, Applied Physiological Laboratory Measurements and Field Measurements of Athletic Performance in Children and Youth: Influences of Growth and Development*, November 16, 2017). All participants, with the help of a parent or legal guardian, completed the 2015 Physical Activity Readiness Questionnaire for Everyone (2015 PAR-Q+) (24) prior to testing. Participants were allowed to partake in the study if questions 1 through 7 or all follow up questions of the PAR-Q+ were answered "no". Each participant was asked to sign an approved youth assent document. Additionally, a parent or guardian of each participant was asked to sign an approved informed consent form.

## Experimental Design

Each participant visited the laboratory twice, separated by 2 to 7 days. The first visit served as a familiarization session, while the second visit was considered experimental and was used to generate the data for the present study. A repeated measures design was used to compare the means of each dependent variable across the jumping conditions: static (SJ), countermovement (CMJ), and rebound drop jumping (DJ). The primary dependent variables were calculated during the concentric phases of each

jumping performance, including peak power, peak rate of force development (RFD), peak force, and concentric impulse. Eccentric impulse was also calculated from the eccentric loading period immediately preceding the concentric phase. The independent variable in this study was the vertical jump condition, for which there were five levels: (a) SJ, (b) CMJ, (c) DJ from 8 inches [DJ8], (d) DJ from 12 inches [DJ12], and (e) DJ from 16 inches [DJ16]. Age, height, body mass, muscle cross-sectional area (CSA), and maturity offset were measured and/or calculated as supporting variables. During the experimental visit, each participant performed two repetitions of each vertical jump condition. The order of vertical jump conditions were randomized. Each participant was given one or two practice repetitions for each condition prior to testing.

Demographics and Anthropometrics

Participant age was calculated from self-reported birth date. Anthropometrics including standing height (cm), seated height (cm), and body mass (kg) were measured at the start of each testing session and were used to estimate PHV. Height and body mass were measured using a digital scale and stadiometer (Seca 769, Hamburg, Germany). Age, body mass, height, and seated height were inserted into the Mirwald regression equation, which has been found reliable for predicting maturity offset (17,19):

$$\begin{gathered}\textit{Maturity Offset} = -[9.236 + 0.0002708 \cdot \textit{Leg Length and Sitting Height interaction}] \\ -[0.001663 \cdot \textit{Age and Leg Length interaction}] \\ +[0.007216 \cdot \textit{Age and Sitting Height interaction}] \\ +[0.02292 \cdot \textit{body mass by height ratio}] \text{ (15)}\end{gathered}$$

Vertical Jump Tests

Two force plates (PASCO PS-2142, PASCO Scientific, Roseville, California) were used to record ground reaction forces during each jump. The Original Step™ (F1005, Marietta, Georgia) adjustable platform was modified to achieve 8-, 12-, and 16-inch (0.2-, 0.3-, and 0.4-m) drop jump heights. The base of the step was four inches (0.1 m) in height and additional risers were added to raise the base in two-inch increments (Figure 3.1). The step was secured to the platform with velcro during the SJ and DJ, but removed during the CMJ (Figure 3.1). The SJ required participants to begin from a squat position with a knee angle of 90° and perform a maximal vertical jump while minimizing any preceding countermovement. The step height was adjusted for each participant to serve as a guide for the staring position, ensuring a 90° knee angle was achieved prior to take off (Figure 3.1). The CMJ required participants to begin in an upright standing position, perform an eccentric phase downward countermovement, and followed by a concentric phase maximal vertical jump. The DJ required participants to begin standing on top of the step adjusted to either 8, 12, or 16 inches (0.2-, 0.3-, and 0.4-m), fall off the step onto the force plates, and immediately perform a maximal vertical jump (11). Participants were instructed to keep their hands on their hips during all jump conditions.

Signal Processing

The y-axis, vertical ground reaction forces were sampled at 1000 Hz from the force plates using PACSO™ Capstone software (PASCO Scientific, Roseville, California). Raw force data was saved (.txt) to a computer after each jump attempt, and

raw force curves were analyzed off-line using a custom-written LabVIEW™ (17.0f1, National Instruments, Austin, Texas) software program. The raw force signals corresponding with the left and right feet were summed to represent whole-body force production, and the summed force signal was used for all subsequent analyses. No digital filtering or smoothing was applied to the summed force signal prior to variable calculations. Variables calculated in the custom software program included concentric peak force (N), concentric peak power (W), concentric peak RFD ($N \cdot s^{-1}$), eccentric impulse (Ns), and concentric impulse (Ns).

Prior to calculating each variable, the investigator (L.E.J.) manually identified three points during the SJ and CMJ force curves, including (a) the initial onset of movement (always downward, negative force), (b) the subsequent zero-crossing of force from negative to positive, and (c) the point at which the feet left the force plates (toe off, zero force). Based on the description of Bobbert et al. (5), the epoch of the force signal from points (a) to (b) was considered the eccentric phase, while the epoch from points (b) to (c) was considered the concentric phase of the SJ and CMJ conditions. The investigator manually identified only two points during the DJ8, DJ12, and DJ16 force curves, including (d) the initial positive force deflection after the subject's free fall and (e) the point at which the feet left the force plates (toe off, zero force). Based on the description of Bobbert et al. (5), the end of the eccentric phase of the DJ8, DJ12, and DJ16 jump conditions was determined as the point at which the force curve crossed a threshold equal to $p_{downward}$ - body mass (N):

$$p_{downward} = \sqrt{\frac{m \cdot g \cdot h}{1/2 \cdot m}} \cdot m$$

where $p_{downward}$ is the vertical force at the end of the eccentric phase after landing, $m$ is mass (kg), $g$ is acceleration due to gravity ($m \cdot s^{-2}$), and $h$ is drop height (m).

After subtracting baseline force (equivalent to body mass), peak force was calculated as the highest concentric force value. Peak RFD was calculated as the highest value ($N \cdot s^{-1}$) of the first derivative of the concentric force-time tracing. Power-time curves were calculated as the product of the force (N) and velocity ($m \cdot s^{-1}$) curves. Peak power was taken as the highest value (W) from the concentric phase of the power-time curve. Eccentric and concentric impulses ($N \cdot s$) were calculated as integrated areas under the eccentric and concentric phases of the force-time curves, respectively. Examples of the raw force curves and the demarcation point separating the concentric and eccentric phases of each jumping condition from subject 11 are presented in Figure 3.2.

Ultrasound Imaging

During each visit, panoramic cross-sectional images of the quadriceps and hamstring were taken to quantify muscle cross sectional area (CSA). The same investigator completed all ultrasound measurements on the right thigh of each participant. Ultrasound images of the leg flexors and extensors were captured using a portable ultrasound imaging device (GE Logiq E, USA) and a multifrequency linear-array probe (12 L-RS, 5–13 MHz, 38.4-mm field-of-view). Participants remained in the supine position for the examination of the quadriceps and the pronated position for the

examination of the hamstrings. The panoramic ultrasound of the quadriceps was taken at two-thirds of the distance from the anterior superior iliac spine (ASIS) and lateral border of the patella beginning at the most lateral aspect of the quadriceps to the most medial aspect of the quadriceps. The panoramic ultrasound of the hamstrings was taken at one-half of the distance from the ischial tuberosity and the lateral epicondyle of the tibia beginning at the most lateral aspect of the hamstrings to the most medial aspect of the hamstrings. During ultrasound examination, participants laid on a padded plinth in a fully relaxed position (Figure 3.3). Ultrasound image analyses were performed by a single investigator using ImageJ Software (Version 1.47v, National Institutes of Health, Bethesda, MD, USA).

Ultrasound images were scaled from pixels to cm using the straight-line function in Image-J prior to analysis. Quadriceps muscle CSA values (rectus femoris, vastus lateralis, vastus intermedius and vastus medialis) and hamstring muscle CSA values (semimembranosus, semitendinosus, and the long head of the bicep femoris) were assessed using the freehand section tool in Image-J and were determined by selecting the maximal region of interest using the rectangle function in the Image-J software (Figure 3.3). This function included as much of the muscle of interest as possible while excluding the surrounding fascia (3). Quadriceps and hamstrings were summed to calculate total muscle CSA.

Statistical Analysis

Means and 95% confidence intervals were calculated and reported for all sample demographics, anthropometrics, muscle CSA, and vertical jump outcomes. Five separate one-way repeated measures analyses of variance (ANOVAs) were used to compare the means for peak power, peak RFD, peak force, concentric impulse, and eccentric impulse across all jumping conditions (SJ versus CMJ versus DJ8 versus DJ12 versus DJ16). When the omnibus ANOVA model indicated a significant difference, post hoc, pairwise, dependent-samples t-tests with Bonferroni corrections were used as follow-up analyses. Delta scores of the peak power values of successive vertical jump conditions were calculated from SJ to CMJ (Delta 1), from CMJ to DJ8 (Delta 2), from DJ8 to DJ12 (Delta 3), and from DJ12 to DJ16 (Delta 4). Relationships among age, height, body mass, maturity offset, muscle CSA, and power delta scores (Delta 1 - 4) were examined with Pearson product moment correlation coefficients. Stepwise multiple regression was used to determine significant variable contributions to the significant power delta scores. Custom Microsoft Excel 2016 worksheets and IBM SPSS v. 23 (Chicago, IL, USA) were used to perform all statistical analyses. An alpha level of $p \leq 0.05$ was considered statistically significant for all analyses.

# CHAPTER IV: RESULTS

Table 4.1 shows the raw data and descriptive statistics for age, height, body mass, maturity offset, and muscle CSA. Tables 4.2, 4.3, 4.4, and 4.5 show the raw data and descriptive statistics for power, RFD, force, and eccentric and concentric impulses, respectively, during the SJ, CMJ, DJ8, DJ12, and DJ16 jumping conditions. Table 4.6 shows the Pearson product moment correlation coefficient matrix among all variables.

ANOVAs indicated that power increased ($F = 27.263$, $p \leq 0.001$, $\eta_p^2 = 0.577$) from SJ to CMJ with no subsequent differences among CMJ, DJ8, DJ12, or DJ16 ($p = 0.686$ - $1.000$) (Figure 4.1-A). RFD and force showed no change from SJ to CMJ ($p = 0.072$ - $0.383$), an increase from CMJ to DJ8 ($F = 51.336$, $p \leq 0.001$, $\eta_p^2 = 0.720$; $F = 68.838$, $p \leq 0.001$, $\eta_p^2 = 0.775$, respectively), but no subsequent changes from DJ8 to DJ12 to DJ16 ($p = 1.00$) (Figures 4.1-B and 4.1-C). Concentric impulse increased from SJ to CMJ ($F = 14.929$, $p \leq 0.001$, $\eta_p^2 = 0.427$), decreased from CMJ to DJ8 ($p = 0.003$), then remained the same from DJ8 to DJ12 to DJ16 ($p = 1.000$). Eccentric impulse increased systematically ($F = 82.488$, $p \leq 0.001$, $\eta_p^2 = 0.805$) from SJ to DJ16 (Figure 4.2).

Based on the significant correlations observed in Table 4.6, stepwise regression indicated that the increase in power from SJ to CMJ (Delta 1) was best explained by height ($R^2 = 0.517$, standard error of the estimate [SEE] = 359.2, $p \leq 0.001$, $y = 21.38$ (height) - $2622.10$) (Figure 4.3). Age ($r = -0.107$, $p = 0.655$), weight ($r = 0.069$, $p = 0.772$), muscle CSA ($r = 0.005$, $p = 0.984$) and maturity offset ($r = 0.023$, $p = 0.924$) did not significantly contribute to the explained variance in Delta 1.

# CHAPTER V: DISCUSSION

The primary findings of the present study were increases in peak power from SJ to CMJ which plateaued from CMJ to DJ16 (Figure 4.1-A), despite systematic increases in eccentric pre-loading (Figure 4.2). Both peak force and peak RFD showed no change from SJ to CMJ, showed an increase from CMJ to DJ8, however showed no further increases to DJ12 and DJ16 (Figure 4.1-B,C). Furthermore, eccentric impulse progressively increased across all jump conditions, while concentric impulse increased from SJ to CMJ, decreased from CMJ to DJ8, and plateaued from DJ8 to DJ16 (Figure 4.2). Therefore, concentric impulse was greatest during the CMJ. Significant correlations were found between delta 1 and age, weight, height, maturity offset, and muscle CSA (Figure 4.6). However, the stepwise regression determined that height best explained the variance in delta 1. Collectively, these findings suggest that the CMJ, the most common method used for assessing vertical jump performance in youth populations, is the optimal jump test for maximizing peak power and concentric work, while minimizing eccentric overload in 6 to 16-year old male youth athletes.

Previous studies have shown increases in power with systematic increases in eccentric pre-loading in adults (6,7,22). In youth populations, the indirect assessment of lower-body power, jump height, has been reported to increase from SJ to CMJ (10,12,21). However, when comparing direct power assessments in boys, the findings of the present study are different to those of Suchomel et al., who demonstrated greater power in the SJ compared to the CMJ among elite male youth gymnasts (21). Whereas, in the present study, power increased from SJ to CMJ and showed no further increase from CMJ to

DJ16 (Figure 4.1-A). Suchomel et al. was different in that the investigators allometrically scaled for body mass, which may help explain the difference in power outcomes as compared to the present study (17). These findings may also suggest variability in motor control in youth populations (17). Suchomel et al. hypothesized that maturity status may have played a role in the young gymnasts' inability to capitalize on the SSC during CMJ (21). The age of the boys sampled in the present study were generally younger than the age of boys sampled for Suchomel et al. study (mean age ± SD = 12.1 ± 2.4 yrs, 15.1± 1.7 yrs, respectively). Lloyd et al. proposed that near puberty there is a decrease in jump performance due to "adolescent awkwardness" in boys (17). This may suggest that the difference in lower-body power reported in Suchomel et al. coincide with possible differences in biological maturity in comparison to the present study (17,16).

Another finding of the present study is that peak RFD did not enhance our understanding of vertical jumping performance. Both peak RFD and peak force demonstrated no change from SJ to CMJ, increases from SJ to DJ8, and no further increases from DJ8 to DJ16 (Figure 4.2-B,C). The fact that both peak RFD and peak force responded the same, likely due to their mathematical relationship, suggests that these variables may be redundant. This supports previous findings from our laboratory that peak RFD provides little, if any, additional information in the assessment of force-time or power-time curves (13).

Previous literature suggests that in adults, power output during the concentric shortening phase may be a result of the energy released during the tendon recoil

following the eccentric pre-load (15,16, 22). The findings of the present study demonstrated systematic increases in eccentric impulse from SJ to DJ16, and concentric impulse increased from SJ to CMJ, then decreased from CMJ to DJ8, with no further differences among DJ heights (Figure 4.2). This may suggest that, in this sample, there was an inability to overcome the increased eccentric pre-load during DJ8 to DJ16 to increase power output. Previous literature also suggests that a lack of motor control may lead to increased mechanical movement of the body during vertical jump assessments in children from SJ to CMJ to DJ (5,18). This may indicate an inability to utilize the SSC during increased eccentric pre-loads.

As stated previously, it has been hypothesized that the youth athletes' ability to use the SSC may be attenuated by age and or maturity (17,18,21). In this sample of 21 boys, stepwise regression indicated height as the single predictor of the significant increment in power from SJ to CMJ. This suggests that growth and development play a large role in SSC utilization for the sample in the present study. Although these variables did not contribute to the prediction model, significant relationships were found between delta1 and PHV maturity offset, age, muscle CSA, and weight. The correlation between delta 1 and PHV maturity offset further suggests that the increase in biological maturity was related to the increase in power due to eccentric pre-loading from SJ to CMJ in this sample (17,18,21). Furthermore, the correlation between delta 1 and muscle CSA may suggest increases in muscle mass are related to increased power output during CMJ versus SJ (7,17). The collinearity PHV and muscle CSA have with height may have limited our ability to ascertain the influence of PHV and muscle CSA on SSC utilization

(Figure 4.6). The results of the present study indicate correlation and not causation, therefore are not generalizable. While the stepwise regression found height to be the best predictor, there is still a large amount of unexplained variance in delta 1. Future studies are needed to experimentally examine the influences PHV and increased muscle CSA have on SSC utilization and power output in this model of increased eccentric pre-loading during vertical jumping.

Based on the findings of the present study, there may be practical implications in that the CMJ may be the best vertical jump test to maximize peak power while limiting eccentric pre-load in males of a similar age. For example, if the goal of the jump assessment is to measure youth athletic performance via power, a countermovement prior to a maximal vertical jump may be a better option than a static jump or drop jump. Additionally, these findings suggest SSC utilization may be heavily influenced by growth and development. Therefore, it may be important to consider growth and development factors when conducting vertical jump assessments with systematic increases in eccentric pre-load in youth populations.

There are limitations to the present study. As a control measure, participants were instructed to keep their hands on their hips during vertical jump tests. Limiting arm movement may not be a natural athletic movement (10). Additionally, participants only received auditory feedback on vertical jump performance. Visual feedback may have further motivated participants to perform a true maximal vertical jump (9). The present study did not assess jump kinematics or measure jump height. Vertical jump performance was based on kinetic vertical jump outcomes. Lastly, the equation used during drop jump

force-curve analysis, where $p_{downward}$ was equal the end of the eccentric phase, makes the assumption that an individual's center of mass (COM) travels the same distance as the height of the drop jump (5).

# FIGURE AND TABLE LEGEND

Figure 3.1: Vertical jump (A) custom-built platform surround two force plates and setup during (B) SJ, (C) CMJ, (D) DJ12.

Figure 3.2: Force-time tracing for subject 11 during static jump (SJ), countermovement jump (CMJ), drop jump from 8in (DJ8), drop jump from 12in (DJ12), and drop jump from 16in (DJ16). Arrows indicate the start of the concentric phase.

Figure 3.3: Ultrasound image of (A) quadricep muscle including rectus femoris (RF), vastus lateralis (VL), vastus intermedius(VI) and vastus medialis (VM), (B) hamstring muscle including semimembranosus (SM), semitendinosus (ST), and the long head of the bicep femoris (LHB), and (C) ultrasound imaging setup.

Figure 4.1: Mean differences of (A) power, (B) RFD, and (C) during static jump (SJ), countermovement jump (CMJ), drop jump from 8in (DJ8), drop jump from 12in (DJ12), and drop jump from 16in (DJ16).

* Indicates a significant increase from SJ

† Indicates significant increase from CMJ

Figure 4.2: Mean differences of eccentric and concentric impulse during static jump (SJ), countermovement jump (CMJ), drop jump from 8in (DJ8), drop jump from 12in (DJ12), and drop jump from 16in (DJ16).

* Indicates a significant increase from SJ

† Indicates significant increase from CMJ

‡ Indicates significant increase from DJ8

¥ Indicates significant increase from DJ12

++ Indicates significant decrease from CMJ ($p = 0.003$)

Figure 4.3: Delta 1, change in power from SJ to CMJ, versus height (cm).

$r = 0.719$, there was a 71.9% positive correlation between delta 1 and height

$R^2 = 0.517$, the variance in delta 1 was related to the variance in height 51.7% of the time

Table 4.1: Descriptive statistics for age, height, weight, maturity offset, muscle cross-sectional area (CSA).

Table 4.2: Descriptive statistics for power during the vertical jump conditions.

Table 4.3: Descriptive statistics for RFD during the vertical jump conditions.

Table 4.4: Descriptive statistics for force during the vertical jump conditions.

Table 4.5: Descriptive statistics for impulse during the vertical jump conditions.

Table 4.6: Pearson product moment correlation coefficient matrix.

Figure 3.1

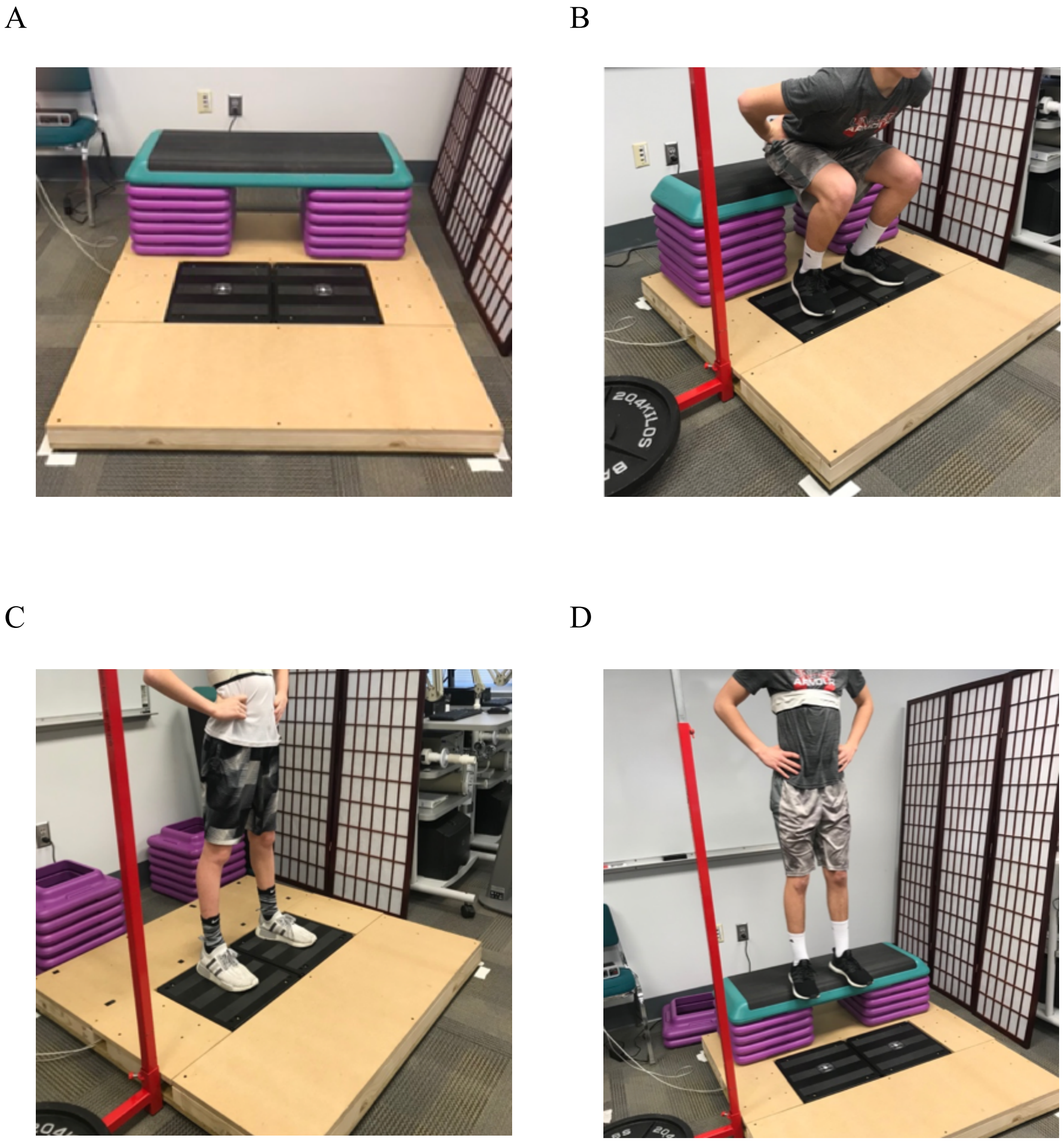


Figure 3.2

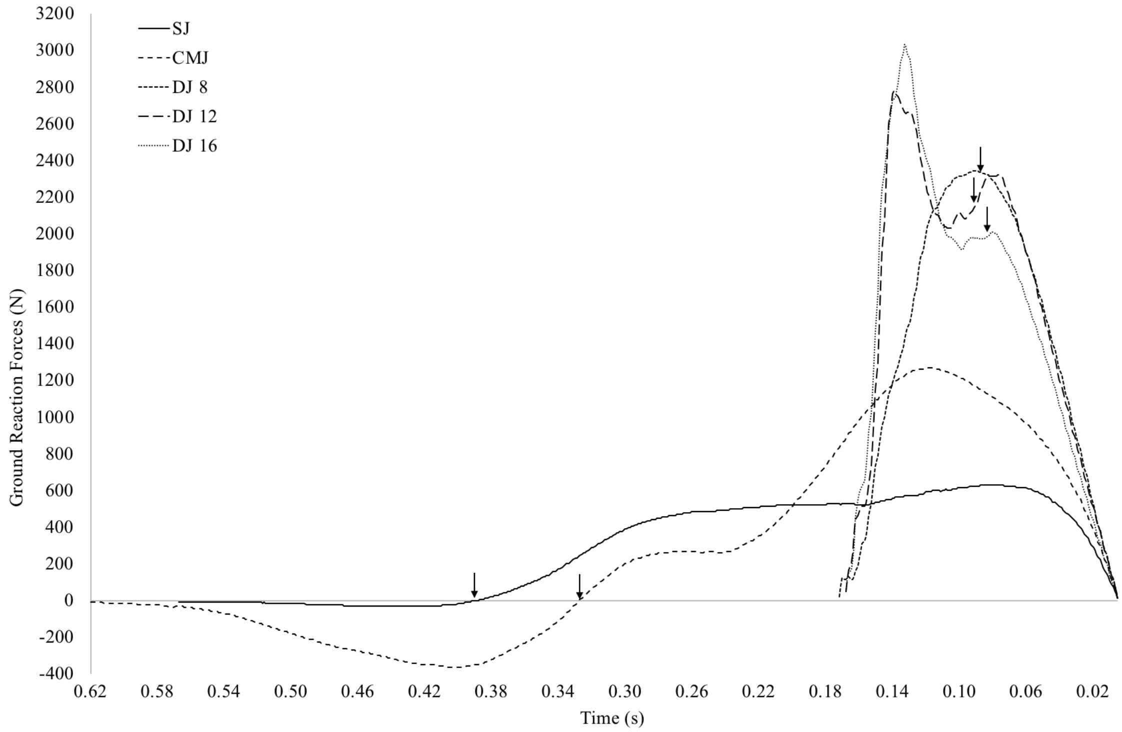
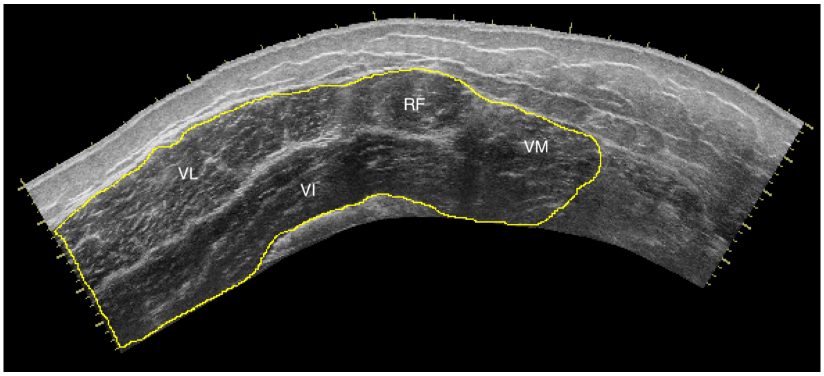
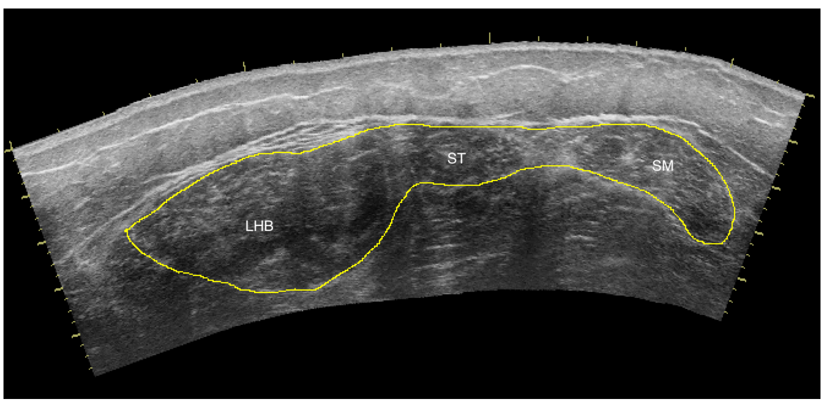

SJ
CMJ
DJ 8
DJ 12
DJ 16
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-200
-400
Ground Reaction Forces (N)
0.62
0.58
0.54
0.50
0.46
0.42
0.38
0.34
0.30
0.26
0.22
0.18
0.14
0.10
0.06
0.02
Time (s)

Figure 3.3

A




B




C

Figure 4.1

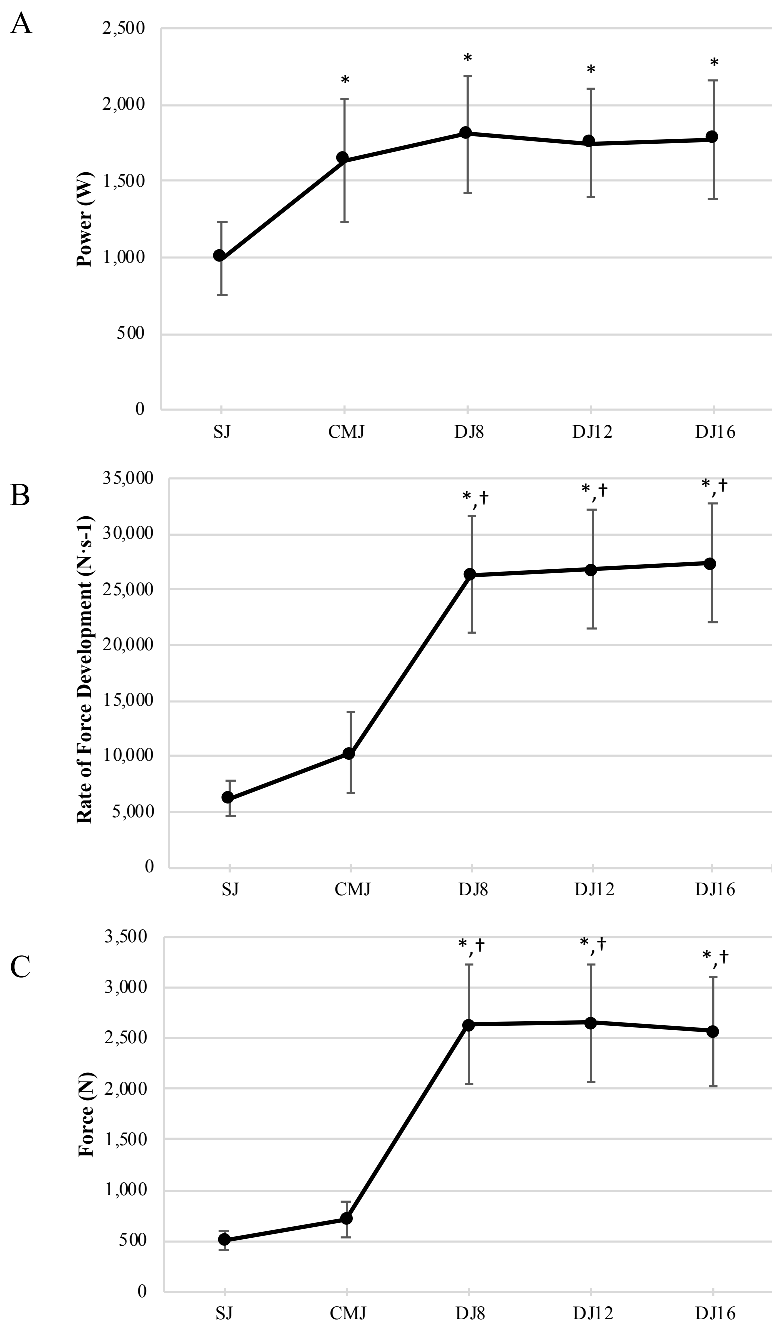

A
Power (W)
2,500
2,000
1,500
1,000
500
0
SJ
CMJ
DJ8
DJ12
DJ16
*
B
Rate of Force Development (N·s-1)
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
SJ
CMJ
DJ8
DJ12
DJ16
*,†
C
Force (N)
3,500
3,000
2,500
2,000
1,500
1,000
500
0
SJ
CMJ
DJ8
DJ12
DJ16
*,†

Figure 4.2

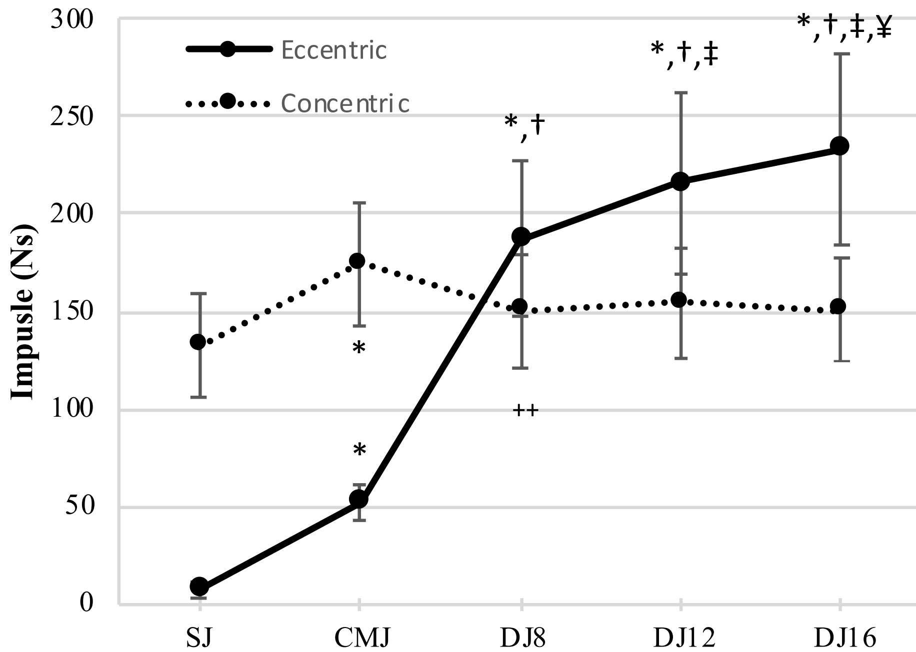
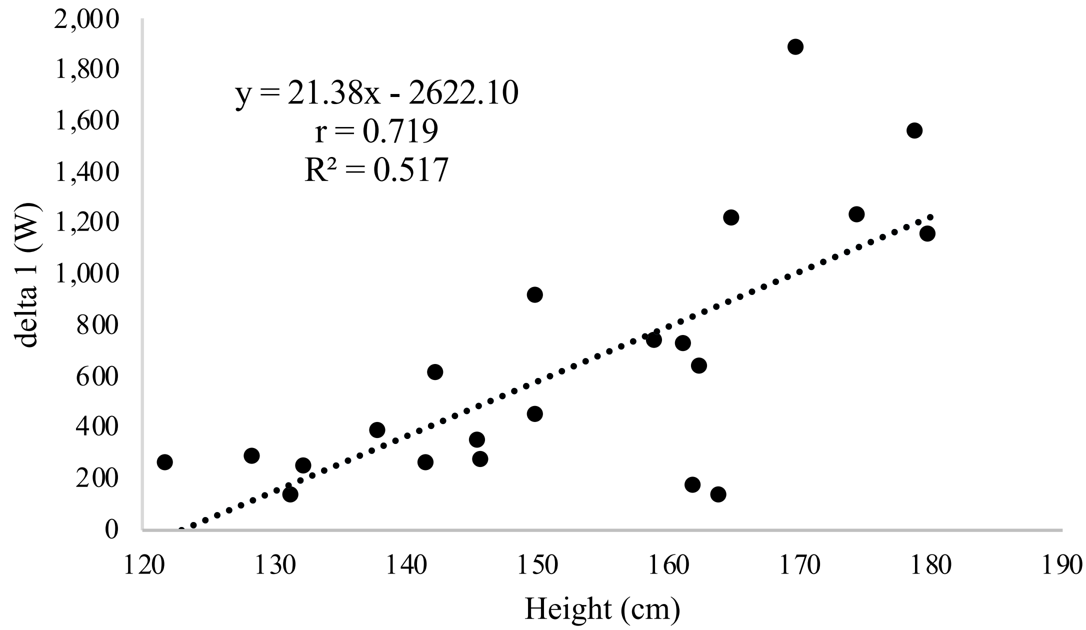

Eccentric
Concentric
Impusle (Ns)
300
250
200
150
100
50
0
SJ
CMJ
DJ8
DJ12
DJ16
*
*
*,†
++
*,†,‡
*,†,‡,¥

Figure 4.3



y = 21.38x - 2622.10
r = 0.719
R² = 0.517
delta 1 (W)
Height (cm)
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
120
130
140
150
160
170
180
190

Table 4.1

| Subject ID | Age (yrs) | Height (cm) | Weight (kg) | Maturity Offset (yrs) | Muscle CSA ($cm^2$) |
|---|---|---|---|---|---|
| 4 | 11.5 | 145.6 | 45.9 | -2.1 | 69.2 |
| 5 | 13.7 | 162 | 62.7 | -0.7 | 74 |
| 6 | 13.7 | 164 | 51.4 | -0.6 | 70.9 |
| 9 | 6.1 | 121.9 | 21.5 | -5.8 | 38.7 |
| 10 | 13 | 150.2 | 37.6 | -1.8 | 57.4 |
| 11 | 15.1 | 169.9 | 60.3 | 0.8 | 81.2 |
| 12 | 16.1 | 179.1 | 73.5 | 2.1 | 97.7 |
| 13 | 12 | 165.1 | 93 | -1.2 | 88.9 |
| 14 | 15.2 | 174.7 | 64.8 | 1.2 | 82.6 |
| 15 | 10.4 | 142.4 | 46.3 | -2.8 | 66 |
| 16 | 13.5 | 162.6 | 68.8 | -0.3 | 113.6 |
| 20 | 13.6 | 180.1 | 86.7 | 0.4 | 95.1 |
| 22 | 11.3 | 146 | 39.3 | -2.5 | 72.4 |
| 24 | 11.2 | 150 | 46.1 | -2.5 | 83 |
| 26 | 13.3 | 159.1 | 64.8 | -0.7 | 75.5 |
| 28 | 9.8 | 138 | 31.8 | -3.6 | 55.9 |
| 29 | 14 | 131.5 | 58.4 | -0.3 | 83.3 |
| 32 | 10.4 | 141.7 | 35.8 | -3.1 | 60.7 |
| 34 | 11.8 | 161.3 | 56.7 | -1.3 | 72.8 |
| 41 | 10.2 | 132.4 | 30.4 | -3.5 | 35.1 |
| 42 | 8.9 | 128.6 | 22 | -4.7 | 27.6 |
| **Mean** | 12.1 | 152.7 | 52.3 | -1.6 | 71.5 |
| **SD** | 2.4 | 17 | 19.5 | 2 | 20.9 |
| **CV** | 19.6 | 11.1 | 37.4 | -125.1 | 29.3 |
| **SEM** | 0.5 | 3.7 | 4.3 | 0.4 | 4.6 |
| **95% CI** | 1.1 | 7.7 | 8.9 | 0.9 | 9.5 |
| **Min** | 6.1 | 121.9 | 21.5 | -5.8 | 27.6 |
| **Max** | 16.1 | 180.1 | 93 | 2.1 | 113.6 |
| **Range** | 10 | 58.2 | 71.5 | 7.8 | 86 |

Table 4.1. Descriptive statistics for age, height, weight, maturity offset, muscle cross-sectional area (CSA).

Table 4.2

| Subject ID | Power (W) | | | | |
|---|---|---|---|---|---|
| | SJ | CMJ | DJ8 | DJ12 | DJ16 |
| 4 | 863.61 | 1207.74 | 1090.44 | 1126.22 | 1160.92 |
| 5 | 1176.06 | 1334.44 | 1085.55 | 1041.61 | 1159.47 |
| 6 | 699.50 | 826.85 | 1372.27 | 1359.32 | 1288.92 |
| 9 | 174.97 | 422.37 | 634.87 | 568.23 | 516.95 |
| 10 | 970.94 | 1417.33 | 1366.24 | 1021.25 | 1399.80 |
| 11 | 1629.81 | 3510.54 | 2902.49 | 3051.50 | 3281.80 |
| 12 | 1941.94 | 3494.65 | 3338.60 | 3235.59 | 3329.42 |
| 13 | 1099.01 | 2314.51 | 2268.06 | 2290.99 | 2178.95 |
| 14 | 1277.25 | 2500.24 | 2543.82 | 2485.64 | 2298.34 |
| 15 | 1026.78 | 1633.94 | 1158.60 | 1249.44 | 1044.13 |
| 16 | 2230.49 | 2866.82 | 2861.56 | 2677.70 | 3656.82 |
| 20 | 1100.38 | 2251.23 | 3400.73 | 2890.49 | 2861.09 |
| 22 | 818.95 | 1081.31 | 1506.42 | 1518.17 | 1546.53 |
| 24 | 541.03 | 1453.83 | 2029.94 | 1792.42 | 1725.43 |
| 26 | 697.46 | 1422.59 | 1719.40 | 1942.67 | 1900.50 |
| 28 | 493.79 | 871.76 | 1194.74 | 1489.80 | 1193.83 |
| 29 | 1349.30 | 1480.90 | 2133.17 | 2038.92 | 1666.24 |
| 32 | 777.30 | 1033.82 | 946.09 | 871.83 | 975.93 |
| 34 | 1269.83 | 1987.57 | 2295.88 | 1879.30 | 1675.22 |
| 41 | 502.36 | 737.62 | 1144.52 | 1016.42 | 1407.96 |
| 42 | 200.37 | 475.61 | 951.94 | 1182.36 | 959.96 |
| **Mean** | 992.43 | 1634.56 | 1806.92 | 1749.04 | 1772.77 |
| **SD** | 521.46 | 898.70 | 834.99 | 774.92 | 864.92 |
| **CV** | 52.54 | 54.98 | 46.21 | 44.31 | 48.79 |
| **SEM** | 113.79 | 196.11 | 182.21 | 169.10 | 188.74 |
| **95% CI** | 236.64 | 407.84 | 378.93 | 351.66 | 392.51 |
| **Min** | 174.97 | 422.37 | 634.87 | 568.23 | 516.95 |
| **Max** | 2230.49 | 3510.54 | 3400.73 | 3235.59 | 3656.82 |
| **Range** | 2055.52 | 3088.17 | 2765.87 | 2667.36 | 3139.87 |

Table 4.2. Descriptive statistics for vertical jump outcome power (W) during static jump (SJ), countermovement jump (CMJ), drop jump from 8in (DJ8), drop jump from 12in (DJ12), and drop jump from 16in (DJ16).

Table 4.3

| Subject ID | Rate of Force Development ($N \cdot s^{-1}$) | | | | |
|---|---|---|---|---|---|
| | SJ | CMJ | DJ8 | DJ12 | DJ16 |
| 4 | 5400.0 | 9795.0 | 18315.0 | 18530.0 | 20215.0 |
| 5 | 7210.0 | 4675.0 | 24670.0 | 19775.0 | 26775.0 |
| 6 | 5005.0 | 4365.0 | 19535.0 | 17960.0 | 16810.0 |
| 9 | 2910.0 | 6225.0 | 7080.0 | 8805.0 | 12635.0 |
| 10 | 6210.0 | 4565.0 | 18230.0 | 18345.0 | 23010.0 |
| 11 | 8070.0 | 27730.0 | 40505.0 | 48120.0 | 42885.0 |
| 12 | 18570.0 | 14220.0 | 53420.0 | 54270.0 | 50820.0 |
| 13 | 5425.0 | 19935.0 | 27325.0 | 30975.0 | 27870.0 |
| 14 | 8640.0 | 11835.0 | 30080.0 | 29185.0 | 28040.0 |
| 15 | 9600.0 | 7985.0 | 27630.0 | 23480.0 | 22820.0 |
| 16 | 7225.0 | 6790.0 | 32215.0 | 35935.0 | 52290.0 |
| 20 | 6155.0 | 6780.0 | 43145.0 | 42315.0 | 35760.0 |
| 22 | 4910.0 | 7665.0 | 23445.0 | 23075.0 | 24490.0 |
| 24 | 3870.0 | 35475.0 | 36840.0 | 21780.0 | 28255.0 |
| 26 | 5805.0 | 6860.0 | 23535.0 | 24935.0 | 20220.0 |
| 28 | 3680.0 | 7180.0 | 13990.0 | 31065.0 | 16545.0 |
| 29 | 4730.0 | 12110.0 | 32525.0 | 25545.0 | 22030.0 |
| 32 | 4580.0 | 7465.0 | 15540.0 | 14630.0 | 16255.0 |
| 34 | 9255.0 | 7455.0 | 36310.0 | 42040.0 | 46765.0 |
| 41 | 2680.0 | 5280.0 | 15160.0 | 13900.0 | 23500.0 |
| 42 | 1395.0 | 2420.0 | 13025.0 | 18800.0 | 15775.0 |
| **Mean** | 6253.6 | 10324.3 | 26310.5 | 26831.7 | 27322.1 |
| **SD** | 3554.8 | 8154.8 | 11518.1 | 11899.0 | 11742.2 |
| **CV** | 56.8 | 79.0 | 43.8 | 44.3 | 43.0 |
| **SEM** | 775.7 | 1779.5 | 2513.4 | 2596.6 | 2562.4 |
| **95% CI** | 1613.2 | 3700.7 | 5227.0 | 5399.9 | 5328.7 |
| **Min** | 1395.0 | 2420.0 | 7080.0 | 8805.0 | 12635.0 |
| **Max** | 18570.0 | 35475.0 | 53420.0 | 54270.0 | 52290.0 |
| **Range** | 17175.0 | 33055.0 | 46340.0 | 45465.0 | 39655.0 |

Table 4.3. Descriptive statistics for vertical jump outcome RFD ($N \cdot s^{-1}$) during static jump (SJ), countermovement jump (CMJ), drop jump from 8in (DJ8), drop jump from 12in (DJ12), and drop jump from 16in (DJ16).

Table 4.4

| Subject ID | Force (N) | | | | |
|---|---|---|---|---|---|
| | SJ | CMJ | DJ8 | DJ12 | DJ16 |
| 4 | 455.30 | 533.06 | 2028.85 | 2389.55 | 2232.38 |
| 5 | 506.18 | 522.48 | 2136.90 | 3087.14 | 2521.93 |
| 6 | 461.11 | 424.75 | 1354.52 | 1556.77 | 1718.49 |
| 9 | 159.95 | 318.53 | 453.74 | 371.87 | 299.81 |
| 10 | 469.61 | 494.88 | 2148.63 | 2372.71 | 2462.87 |
| 11 | 684.98 | 1826.84 | 3260.59 | 4063.16 | 4417.89 |
| 12 | 964.81 | 1209.78 | 6099.16 | 5750.53 | 5060.58 |
| 13 | 601.78 | 1455.06 | 3622.86 | 2372.69 | 2640.76 |
| 14 | 615.20 | 1077.25 | 3047.29 | 2807.22 | 2652.76 |
| 15 | 596.13 | 560.41 | 2823.71 | 2551.46 | 2184.85 |
| 16 | 932.30 | 885.80 | 4081.08 | 4306.52 | 4611.69 |
| 20 | 619.75 | 803.54 | 4716.86 | 4450.45 | 4142.27 |
| 22 | 480.39 | 387.05 | 2402.85 | 2337.37 | 2398.09 |
| 24 | 337.31 | 863.59 | 1530.43 | 1839.41 | 1598.88 |
| 26 | 453.37 | 621.95 | 2938.68 | 2597.99 | 2666.40 |
| 28 | 300.24 | 414.35 | 1189.61 | 1153.39 | 1615.68 |
| 29 | 520.66 | 820.92 | 2833.35 | 3140.70 | 2526.01 |
| 32 | 371.30 | 434.66 | 2638.39 | 2606.70 | 2438.03 |
| 34 | 674.37 | 672.77 | 3081.78 | 3396.04 | 3306.25 |
| 41 | 323.93 | 435.67 | 1584.13 | 1287.81 | 1395.52 |
| 42 | 153.01 | 189.93 | 1311.63 | 1229.39 | 1029.26 |
| **Mean** | 508.65 | 712.06 | 2632.62 | 2650.90 | 2567.64 |
| **SD** | 208.64 | 403.40 | 1299.96 | 1266.85 | 1196.50 |
| **CV** | 41.02 | 56.65 | 49.38 | 47.79 | 46.60 |
| **SEM** | 45.53 | 88.03 | 283.67 | 276.45 | 261.10 |
| **95% CI** | 94.68 | 183.07 | 589.93 | 574.91 | 542.98 |
| **Min** | 153.01 | 189.93 | 453.74 | 371.87 | 299.81 |
| **Max** | 964.81 | 1826.84 | 6099.16 | 5750.53 | 5060.58 |
| **Range** | 811.81 | 1636.92 | 5645.42 | 5378.66 | 4760.77 |

Table 4.4. Descriptive statistics for vertical jump outcome F (N) during static jump (SJ), countermovement jump (CMJ), drop jump from 8in (DJ8), drop jump from 12in (DJ12), and drop jump from 16in (DJ16).

Table 4.5

| Subject ID | Eccentric Impulse (Ns) | | | | | Concentric Impulse (Ns) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SJ | CMJ | DJ8 | DJ12 | DJ16 | SJ | CMJ | DJ8 | DJ12 | DJ16 |
| 4 | 4.7 | 44.5 | 170.4 | 194.0 | 218.1 | 122.0 | 144.6 | 132.3 | 151.9 | 145.3 |
| 5 | 26.3 | 62.1 | 400.6 | 467.4 | 435.9 | 176.6 | 197.9 | 177.4 | 240.7 | 185.0 |
| 6 | 6.7 | 39.5 | 198.0 | 198.8 | 232.5 | 108.2 | 143.8 | 105.5 | 118.4 | 137.2 |
| 9 | 4.0 | 12.9 | 67.6 | 81.2 | 87.3 | 33.6 | 46.8 | 40.1 | 36.1 | 34.9 |
| 10 | 1.5 | 42.0 | 139.7 | 185.5 | 156.5 | 102.8 | 138.5 | 115.8 | 134.8 | 126.7 |
| 11 | 2.9 | 44.4 | 201.5 | 208.4 | 221.9 | 177.8 | 196.3 | 153.2 | 167.3 | 185.9 |
| 12 | 2.4 | 93.2 | 217.7 | 255.8 | 290.5 | 195.9 | 288.1 | 257.9 | 248.3 | 227.7 |
| 13 | 22.9 | 53.0 | 381.1 | 445.5 | 504.4 | 233.0 | 243.7 | 262.7 | 183.4 | 208.5 |
| 14 | 9.8 | 58.1 | 188.6 | 217.1 | 255.8 | 169.4 | 211.9 | 173.9 | 163.4 | 165.2 |
| 15 | 1.3 | 51.9 | 211.8 | 228.3 | 268.3 | 105.6 | 166.0 | 163.7 | 152.7 | 144.6 |
| 16 | 14.0 | 87.0 | 225.0 | 283.7 | 254.9 | 215.6 | 297.4 | 213.1 | 220.8 | 199.6 |
| 20 | 1.7 | 84.6 | 265.0 | 330.7 | 357.6 | 215.3 | 302.0 | 246.8 | 261.6 | 244.5 |
| 22 | 0.7 | 51.9 | 122.3 | 138.9 | 150.2 | 90.7 | 146.6 | 125.9 | 128.1 | 123.0 |
| 24 | 1.8 | 54.5 | 130.3 | 162.7 | 182.1 | 96.4 | 151.1 | 92.3 | 112.8 | 99.5 |
| 26 | 2.5 | 60.9 | 249.6 | 253.0 | 281.2 | 132.0 | 194.6 | 199.4 | 187.2 | 199.2 |
| 28 | 0.5 | 34.6 | 100.4 | 104.1 | 125.4 | 69.9 | 103.6 | 71.7 | 72.6 | 94.9 |
| 29 | 16.5 | 56.4 | 193.1 | 212.3 | 263.2 | 184.5 | 185.7 | 157.9 | 186.1 | 174.7 |
| 32 | 21.0 | 47.9 | 136.5 | 171.5 | 171.2 | 102.5 | 140.2 | 160.4 | 168.4 | 159.0 |
| 34 | 1.3 | 59.5 | 175.9 | 217.4 | 256.8 | 142.2 | 202.2 | 156.8 | 182.2 | 192.6 |
| 41 | 2.8 | 34.5 | 89.9 | 108.0 | 105.8 | 65.6 | 100.7 | 86.0 | 76.7 | 68.1 |
| 42 | 0.9 | 20.3 | 59.6 | 69.8 | 81.1 | 39.5 | 64.8 | 61.7 | 53.1 | 51.6 |
| **Mean** | 7.0 | 52.1 | 186.9 | 215.9 | 233.4 | 132.3 | 174.6 | 150.2 | 154.6 | 150.8 |
| **SD** | 8.1 | 19.8 | 88.5 | 103.2 | 107.5 | 58.8 | 69.8 | 63.0 | 62.2 | 57.1 |
| **CV** | 117.0 | 38.0 | 47.4 | 47.8 | 46.1 | 44.4 | 40.0 | 41.9 | 40.2 | 37.9 |
| **SEM** | 1.8 | 4.3 | 19.3 | 22.5 | 23.5 | 12.8 | 15.2 | 13.8 | 13.6 | 12.5 |
| **95% CI** | 3.7 | 9.0 | 40.2 | 46.8 | 48.8 | 26.7 | 31.7 | 28.6 | 28.2 | 25.9 |
| **Min** | 0.5 | 12.9 | 59.6 | 69.8 | 81.1 | 33.6 | 46.8 | 40.1 | 36.1 | 34.9 |
| **Max** | 26.3 | 93.2 | 400.6 | 467.4 | 504.4 | 233.0 | 302.0 | 262.7 | 261.6 | 244.5 |
| **Range** | 25.8 | 80.3 | 341.0 | 397.6 | 423.2 | 199.4 | 255.2 | 222.6 | 225.5 | 209.7 |

Table 4.5. Descriptive statistics for vertical jump outcomes including eccentric impulse (Ns) and concentric impulse (Ns) during static jump (SJ), countermovement jump (CMJ), drop jump from 8in (DJ8), drop jump from 12in (DJ12), and drop jump from 16in (DJ16).

Table 4.6

| | | delta 1 | delta 2 | delta 3 | delta 4 | CSA | Age (yrs) |
|---|---|---|---|---|---|---|---|
| delta 1 | Pearson Correlation | 1.000 | -0.284 | -0.094 | 0.068 | .551** | .543* |
| | Sig. (2-tailed) | | 0.211 | 0.684 | 0.771 | 0.010 | 0.011 |
| delta 2 | Pearson Correlation | -0.284 | 1.000 | -0.350 | -0.281 | -0.066 | -0.151 |
| | Sig. (2-tailed) | 0.211 | | 0.120 | 0.217 | 0.777 | 0.514 |
| delta 3 | Pearson Correlation | -0.094 | -0.350 | 1.000 | -0.264 | -0.321 | -0.203 |
| | Sig. (2-tailed) | 0.684 | 0.120 | | 0.248 | 0.156 | 0.378 |
| delta 4 | Pearson Correlation | 0.068 | -0.281 | -0.264 | 1.000 | 0.261 | 0.192 |
| | Sig. (2-tailed) | 0.771 | 0.217 | 0.248 | | 0.253 | 0.405 |
| CSA | Pearson Correlation | .551** | -0.066 | -0.321 | 0.261 | 1.000 | .741** |
| | Sig. (2-tailed) | 0.010 | 0.777 | 0.156 | 0.253 | | 0.000 |
| Age (yrs) | Pearson Correlation | .543* | -0.151 | -0.203 | 0.192 | .741** | 1.000 |
| | Sig. (2-tailed) | 0.011 | 0.514 | 0.378 | 0.405 | 0.000 | |
| Height (cm) | Pearson Correlation | .719** | -0.120 | -0.314 | 0.190 | .762** | .815** |
| | Sig. (2-tailed) | 0.000 | 0.604 | 0.166 | 0.409 | 0.000 | 0.000 |
| Weight (kg) | Pearson Correlation | .625** | -0.024 | -0.283 | 0.080 | .849** | .723** |
| | Sig. (2-tailed) | 0.002 | 0.918 | 0.213 | 0.730 | 0.000 | 0.000 |
| Maturity Offset (yrs) | Pearson Correlation | .640** | -0.130 | -0.251 | 0.150 | .813** | .975** |
| | Sig. (2-tailed) | 0.002 | 0.575 | 0.273 | 0.517 | 0.000 | 0.000 |

Table 4.6. Pearson product moment correlations for delta 1 (SJ to CMJ), delta 2 (CMJ to DJ8), delta 3 (DJ8 to DJ12), delta 4 (DJ12 to DJ16), muscle cross-sectional area (CSA), age, height, weight, and maturity offset.

*Indicates correlation is significant at the 0.05 level (2-tailed)

**Indicates correlation is significant at the 0.01 level (2-tailed)

# REFERENCES


1. Asmussen, E and Bonde-Petersen, F. Storage of elastic energy in skeletal muscles in man. Acta Physiol 91: 385–392, 1974.
2. Baker, D. Improving vertical jump performance through general, special, and specific strength training. J Strength Cond Res 10: 131–136, 1996.
3. Bernardi, SP. Dynamic High resolution Sonography (d-HRUS) of lower limb muscles: a detailed didactic approach. , 2014.Available from: http://posterng.netkey.at/esr/viewing/index.php?module=viewing_poster&task=viewsection&pi=119799&ti=402657&searchkey
4. Bobbert, MF, Huijing, PA, and van Ingen Schenau, GJ. Drop jumping. I. The influence of jumping technique on the biomechanics of jumping. Med Sci Sports Exerc 19: 332–338, 1987.
5. Bobbert, MF, Huijing, PA, and Van, GIS. Drop jumping. II. The influence of dropping height on the biomechanics of drop jumping. Med Sci Sports Exerc 19: 339–346, 1987.
6. Bosco, C, Montanari, G, Ribacchi, R, Giovenali, P, Latteri, F, Iachelli, G, et al. Relationship between the efficiency of muscular work during jumping and the energetics of running. Eur J Appl Physiol 56: 138–143, 1987.
7. Bosco, C, Tihanyi, J, Komi, PV, Fekete, G, and Apor, P. Store and recoil of elastic energy in slow and fast types of human skeletal muscles. Acta Physiol 116: 343–349, 1982.

8. Byrne, PJ, Moran, K, Rankin, P, and Kinsella, S. A comparison of methods used to identify ‘optimal’drop height for early phase adaptations in depth jump training. J Strength Cond Res 24: 2050–2055, 2010.
9. Ford, KR, Myer, GD, Smith, RL, and Byrnes, RN. Use of an overhead goal alters vertical jump performance and biomechanics. J Strength Cond Res 19: 394, 2005.
10. Gerodimos, V, Zafeiridis, A, Perkos, S, Dipla, K, Manou, V, and Kellis, S. The contribution of stretch-shortening cycle and arm-swing to vertical jumping performance in children, adolescents, and adult basketball players. Pediatr Exerc Sci 20: 379–389, 2008.
11. Haff. Essentials of Strength Training and Conditioning 4th Edition With Web Resource -. Hum.-Kinet. , 2015.Available from: http://www.humankinetics.com/products/all-products/essentials-of-strength-training-and-conditioning-4th-edition-with-web-resource
12. Harrison, AJ and Gaffney, S. Motor development and gender effects on stretch-shortening cycle performance. J Sci Med Sport 4: 406–415, 2001.
13. Jenkins, NDM, Housh, TJ, Traylor, DA, Cochrane, KC, Bergstrom, HC, Lewis, RW, et al. The rate of torque development: a unique, non-invasive indicator of eccentric-induced muscle damage? Int J Sports Med 35: 1190–1195, 2014.
14. Jensen, RL and Ebben, WP. Quantifying plyometric intensity via rate of force development, knee joint, and ground reaction forces. J Strength Cond Res 21: 763, 2007.

15. Komi, PV and Bosco, C. Utilization of stored elastic energy in leg extensor muscles by men and women. Med Sci Sports 10: 261–265, 1978.
16. Kubo, K, Kawakami, Y, and Fukunaga, T. Influence of elastic properties of tendon structures on jump performance in humans. J Appl Physiol Bethesda Md 1985 87: 2090–2096, 1999.
17. Lloyd, RS, Oliver, JL, Hughes, MG, and Williams, CA. The influence of chronological age on periods of accelerated adaptation of stretch-shortening cycle performance in pre and postpubescent boys. J Strength Cond Res 25: 1889–1897, 2011.
18. Meylan, CM, Cronin, JB, Oliver, JL, Hughes, MG, and McMaster, Dt. The Reliability of Jump Kinematics and Kinetics in Children of Different Maturity Status. J Strength Cond Res 26: 1015, 2012.
19. Mirwald, RL, Baxter-Jones, ADG, Bailey, DA, and Beunen, GP. An assessment of maturity from anthropometric measurements. Med Sci Sports Exerc 34: 689–694, 2002.
20. Peterson, MD, Alvar, BA, and Rhea, MR. The contribution of maximal force production to explosive movement among young collegiate athletes. J Strength Cond Res 20: 867, 2006.
21. Suchomel, TJ, Sands, WA, and McNeal, JR. COMPARISON OF STATIC, COUNTERMOVEMENT, AND DROP JUMPS OF THE UPPER AND LOWER EXTREMITIES IN US JUNIOR NATIONAL TEAM MALE GYMNASTS. Sci Gymnast J 8, 2016.

22. Turner, AN and Jeffreys, I. The stretch-shortening cycle: Proposed mechanisms and methods for enhancement. Strength Cond J 32: 87–99, 2010.

23. Walsh, M, Arampatzis, A, Schade, F, and BrÜggemann, G. The effect of drop jump starting height and contact time on power, work performed, and moment of force. J Strength Cond Res 18: 561–566, 2004.

24. Warburton, DER, Jamnik, V, Bredin, SSD, Shephard, RJ, and Gledhill, N. The 2015 Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and electronic Physical Activity Readiness Medical Examination (ePARmed-X+). Health Fit J Can 8: 53–56, 2015.

25. Wathen, D. Literature review: explosive/plyometric exercises. Training 25: 122, 1993.

APPENDIX A

# 2015 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

## GENERAL HEALTH QUESTIONS

| **Please read the 7 questions below carefully and answer each one honestly: check YES or NO.** | **YES** | **NO** |
|---|---|---|
| 1) Has your doctor ever said that you have a heart condition ☐ OR high blood pressure ☐? | ☐ | ☐ |
| 2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity? | ☐ | ☐ |
| 3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise). | ☐ | ☐ |
| 4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** ______ | ☐ | ☐ |
| 5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** ______ | ☐ | ☐ |
| 6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it ***does not limit your current ability*** to be physically active. **PLEASE LIST CONDITION(S) HERE:** ______ | ☐ | ☐ |
| 7) Has your doctor ever said that you should only do medically supervised physical activity? | ☐ | ☐ |

**If you answered NO to all of the questions above, you are cleared for physical activity.**
**Go to Page 4 to sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.**

- Start becoming much more physically active – start slowly and build up gradually.
- Follow International Physical Activity Guidelines for your age (www.who.int/dietphysicalactivity/en/).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

**If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.**

**Delay becoming more active if:**

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at **www.eparmedx.com** before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

OSHF

# 2015 PAR-Q+

## FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

**1. Do you have Arthritis, Osteoporosis, or Back Problems?**
If the above condition(s) is/are present, answer questions 1a-1c If **NO** ☐ go to question 2

| | | |
|---|---|---|
| 1a. | Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) | YES ☐ NO ☐ |
| 1b. | Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)? | YES ☐ NO ☐ |
| 1c. | Have you had steroid injections or taken steroid tablets regularly for more than 3 months? | YES ☐ NO ☐ |

**2. Do you have Cancer of any kind?**
If the above condition(s) is/are present, answer questions 2a-2b If **NO** ☐ go to question 3

| | | |
|---|---|---|
| 2a. | Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and neck? | YES ☐ NO ☐ |
| 2b. | Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)? | YES ☐ NO ☐ |

**3. Do you have a Heart or Cardiovascular Condition?** *This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm*
If the above condition(s) is/are present, answer questions 3a-3d If **NO** ☐ go to question 4

| | | |
|---|---|---|
| 3a. | Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) | YES ☐ NO ☐ |
| 3b. | Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction) | YES ☐ NO ☐ |
| 3c. | Do you have chronic heart failure? | YES ☐ NO ☐ |
| 3d. | Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months? | YES ☐ NO ☐ |

**4. Do you have High Blood Pressure?**
If the above condition(s) is/are present, answer questions 4a-4b If **NO** ☐ go to question 5

| | | |
|---|---|---|
| 4a. | Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) | YES ☐ NO ☐ |
| 4b. | Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure) | YES ☐ NO ☐ |

**5. Do you have any Metabolic Conditions?** *This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes*
If the above condition(s) is/are present, answer questions 5a-5e If **NO** ☐ go to question 6

| | | |
|---|---|---|
| 5a. | Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies? | YES ☐ NO ☐ |
| 5b. | Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness. | YES ☐ NO ☐ |
| 5c. | Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet? | YES ☐ NO ☐ |
| 5d. | Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)? | YES ☐ NO ☐ |
| 5e. | Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future? | YES ☐ NO ☐ |

 
01-01-2015

# 2015 PAR-Q+

| | | |
|---|---|---|
| **6.** | **Do you have any Mental Health Problems or Learning Difficulties?** *This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome* | |
| | If the above condition(s) is/are present, answer questions 6a-6b | If **NO** ☐ go to question 7 |
| 6a. | Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) | **YES** ☐ **NO** ☐ |
| 6b. | Do you **ALSO** have back problems affecting nerves or muscles? | **YES** ☐ **NO** ☐ |
| **7.** | **Do you have a Respiratory Disease?** *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure* | |
| | If the above condition(s) is/are present, answer questions 7a-7d | If **NO** ☐ go to question 8 |
| 7a. | Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) | **YES** ☐ **NO** ☐ |
| 7b. | Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy? | **YES** ☐ **NO** ☐ |
| 7c. | If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week? | **YES** ☐ **NO** ☐ |
| 7d. | Has your doctor ever said you have high blood pressure in the blood vessels of your lungs? | **YES** ☐ **NO** ☐ |
| **8.** | **Do you have a Spinal Cord Injury?** *This includes Tetraplegia and Paraplegia* | |
| | If the above condition(s) is/are present, answer questions 8a-8c | If **NO** ☐ go to question 9 |
| 8a. | Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) | **YES** ☐ **NO** ☐ |
| 8b. | Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting? | **YES** ☐ **NO** ☐ |
| 8c. | Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)? | **YES** ☐ **NO** ☐ |
| **9.** | **Have you had a Stroke?** *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event* | |
| | If the above condition(s) is/are present, answer questions 9a-9c | If **NO** ☐ go to question 10 |
| 9a. | Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) | **YES** ☐ **NO** ☐ |
| 9b. | Do you have any impairment in walking or mobility? | **YES** ☐ **NO** ☐ |
| 9c. | Have you experienced a stroke or impairment in nerves or muscles in the past 6 months? | **YES** ☐ **NO** ☐ |
| **10.** | **Do you have any other medical condition not listed above or do you have two or more medical conditions?** | |
| | If you have other medical conditions, answer questions 10a-10c | If **NO** ☐ read the Page 4 recommendations |
| 10a. | Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months? | **YES** ☐ **NO** ☐ |
| 10b. | Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)? | **YES** ☐ **NO** ☐ |
| 10c. | Do you currently live with two or more medical conditions? | **YES** ☐ **NO** ☐ |

**PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE:** ____________________

**GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.**



# 2015 PAR-Q+

**If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:**

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:

You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

**Delay becoming more active if:**

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

## PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

*I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider, or other designate) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that the Trustee maintains the privacy of the information and does not misuse or wrongfully disclose such information.*

NAME ______________________________ DATE ______________________

SIGNATURE __________________________ WITNESS ___________________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ______________________

**For more information, please contact**

**www.eparmedx.com**
**Email: eparmedx@gmail.com**

**Citation for PAR-Q+**
Warburton DER, Jamnik VK, Bredin SSD, and Gledhill N on behalf of the PAR-Q+ Collaboration. The Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and Electronic Physical Activity Readiness Medical Examination (ePARmed-X+). Health & Fitness Journal of Canada 4(2):3-23, 2011.

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or the BC Ministry of Health Services.

**Key References**
1. Jamnik VK, Warburton DER, Makarski J, McKenzie DC, Shephard RJ, Stone J, and Gledhill N. Enhancing the effectiveness of clearance for physical activity participation; background and overall process. APNM 36(S1):S3-S13, 2011.
2. Warburton DER, Gledhill N, Jamnik VK, Bredin SSD, McKenzie DC, Stone J, Charlesworth S, and Shephard RJ. Evidence-based risk assessment and recommendations for physical activity clearance; Consensus Document. APNM 36(S1):S266-s298, 2011.

APPENDIX B

IRB #20171017495EP

**Title of Research Study**
Changes in noninvasive, applied physiological laboratory measurements and field measurements of athletic performance in children and youth: Influences of growth and development

**Invitation to Participate**
Your child/legal ward is invited to participate in this research study. The following is provided in order to help you make an informed decision whether or not to allow your child/legal ward to participate. If you have any questions, please do not hesitate to ask.

**Basis for Subject Selection**
Your child/legal ward was selected as a potential volunteer because he or she is 5-18 years of age, in good health, and participates in youth sports. If you wish to allow your child/legal ward to participate you must fill out a physical activity readiness questionnaire (The Physical Activity Readiness Questionnaire for Everyone, PAR-Q+). Your child/legal ward will be prevented from participating in this research study if there are indications from PAR-Q+ that he or she may have health risks. Such indications include heart conditions, high blood pressure, chest pain, dizziness not associated with over-breathing or exercise, loss of consciousness, other chronic medical conditions, a current or recent (previous 12 months) bone, joint, or soft tissue problem that could be made worse by exercise, or if his/her doctor has said he/she should only do medically supervised exercise. Muscle or skeletal disorders including previous or current wrist, elbow, shoulder, spine, hip, knee, and/or ankle injuries may also preclude your child/legal ward from participation in this study. A pacemaker or metal implant in the upper extremities will also preclude your child/legal ward from participation in this study. If your child/legal ward has no muscle/skeletal disorders or disease that will prevent him or her from engaging in physical activity, he or she will be asked to perform the physical tests described below. Overall, there are numerous health-related issues that may preclude your child/legal ward from participation in this study and inclusion will be determined on a subject-by-subject basis.

NOTE for all parents and/or legal guardians:

Consent to allow your child/legal ward to participate in this research study is consenting to the use of the testing results as data. If your child is signed up for the testing, he or she will complete the tests outlined in this document.

**Purpose of the Study**

To investigate:

- The influences of growth and development on noninvasive laboratory and field tests. The noninvasive laboratory tests will assess leg strength and muscle activity during leg extension and leg curl exercises. The field tests include common athletic performance agility, speed, and power tests. The combination of laboratory and field tests will give us insight into the role of growth and development on muscle strength, power, and muscle activity.

**Explanation of Procedures**

Exercise Tests and Body Measurements:

Your child/legal ward will be asked by their sports organization to complete a series of assessments commonly used in laboratory and field testing. These assessments include:

- Height, weight, seated height, ultrasound of the thigh muscles, and measurements of skinfolds, limb lengths, and circumferences.
    - The ultrasound will be in diagnostic mode and will be completely painless and noninvasive.
- Leg extension and leg curl exercises
    - During these exercises, we will have sensors placed on one quad muscle and one hamstring muscle. These sensors measure the activity of the muscle and are 10 millimeters in diameter and are passive and noninvasive.
- Vertical jumps (countermovement jump, drop jump, and/or static jump)
- Power push-up (a push-up on a device that measures power)

NOTE: We ask that your child/legal ward come dressed for exercise including shorts, t-shirt, and athletic shoes.

**Data Retention**

Long-Term Data Analysis:

If your child/legal ward participates in more than one testing session, we will compile his/her results over time for long-term analysis. Your child/legal ward's identifying information will be maintained on a master list until it is destroyed at the conclusion of this study.

**Total Time Commitment**

Testing involves 2 testing sessions within a 1week time frame, separated by at least 48 hours. The total time commitment for each of the testing sessions is about 60-90 minutes. The testing session will be performed at Ruth Leverton Hall on the University of Nebraska-Lincoln East Campus. After this session is complete, we will schedule the next visit at least 48 hours later.

**Potential Risks and Discomforts**
The following are the potential risks and discomforts your child/legal ward may experience during this study:

- There are no known risks associated with the exercise tests that are greater than those ordinarily encountered in youth sport activities.
- Heavy exercise can cause high or low blood pressure, fainting, irregular heart rhythm, chest pain, and very rarely, heart attack, stroke or cardiac arrest. The need for hospital admission is reported in less than six of every 10,000 exercise tests. Cardiac arrest is reported in less than one of every 10,000 exercise tests.

**Protection Against Risks**
Throughout all tests, your child/legal ward will be monitored by personnel trained in Cardiopulmonary Resuscitation (CPR) and the use of an automated external defibrillator (AED). In addition, your child/legal ward will be asked repeatedly if he or she feels he or she can continue the tests. In the unlikely event that your child/legal ward should suffer an injury as a direct consequence of the research procedures, the acute medical care required to treat the injury can be provided at local health care facilities. If the health care facilities are unable to treat your child/legal ward, emergency care is available at local community health providers.  The costs of such care will be your responsibility.

**Potential Benefits to Subjects**
If you decide to allow your child/legal ward to participate in this research study, you will have the opportunity to receive information about your child/legal ward's performance on specific tests from qualified exercise professionals who are certified, or have completed a college course in strength and conditioning.

Your child/legal ward will also be helping to advance the research about long-term changes in performance due to growth and development.

**Subject Compensation**
Your child/legal ward will be compensated $10 cash for each test visit ($20 total).

**In Case of Emergency Contact Procedures**
If your child/legal ward is injured while at the study site, one of the investigators will contact a local health care provider. You may (and should) always contact any of the investigators listed at the end of this consent form if you have any questions.

**Medical Care in Case of Injury**
In the unlikely event that your child/legal ward should suffer an injury as a direct consequence of the research procedures described above, the acute medical care required to treat the injury will be provided by the local community health care providers or your

child/legal ward's personal health care provider. The cost of such medical care will be your responsibility.

**Assurance of Confidentiality**

A copy of specific test results will be provided to you and your child/legal ward.

After the test results have been released to the parties listed above, any information obtained from this study which could identify your child/legal ward will be kept strictly confidential. The information may be published in scientific journals or presented at scientific meetings, but your child/legal ward's identity will be kept strictly confidential. All data collected as a result of your child/legal ward's participation will be kept in a locked cabinet in the office of the primary investigator (Room 211 Ruth Leverton Hall). Your child/legal ward's data will receive an identifying number that is separate from the one used during data collection and only the investigators will be able to identify your child/legal ward from his or her data. The master list of identifying numbers will be stored separately from the data in a locked cabinet and will be destroyed at the conclusion of this research project. Your child/legal ward's data will be compiled and only group data will be used for dissemination without identifying your child/legal ward's name. For the purposes of future reference, your child/legal ward's data will be stored for a minimum of 15 years.

**Rights of Research Subjects**

You may ask any questions concerning this research and have those questions answered before agreeing to allow your child/legal ward to participate in or during the study. Or you may call the investigator, Dr. Joel Cramer at his office phone, (402) 472-7533. You may also contact Zack Gillen at his office phone, (402) 472-7738. Please contact the investigators:

- If you want to voice concerns or complaints about the research.
- In the event of a research related injury.

Please contact the University of Nebraska-Lincoln Institutional Review Board at (402) 472-6965 for the following reasons:

- You wish to talk to someone other than the research staff to obtain answers to questions about your child/legal ward's rights as a research participant.
- To voice concerns or complaints about the research.
- To provide input concerning the research process.
- In the event the study staff could not be reached.

**Voluntary Participation Withdrawal**

You are free to decide not to allow your child/legal ward to participate in this study, or to withdraw your child/legal ward at any time without adversely affecting his or her relationship with the investigators or the University of Nebraska.

You are voluntarily making a decision whether or not to allow your child/legal ward to participate in this research study. Your signature certifies that the content and meaning of the information on this consent form have been fully explained to you and that you have decided to allow your child to participate having read and understood the information presented. Your signature also certifies that you have had all your questions answered to your satisfaction. If you think of any questions during this study, please contact the investigators. You will be given a copy of this consent form to keep.

Name of Child to be Included:

________________________________________

(Name of Child: Please print)

**Name & Signature of Parent/Legal Guardian:**

________________________________________

(Name of Parent/Legal Guardian: Please print)

________________________________________ _____________

(Signature of Parent/Legal Guardian) Date

**Investigators:**

| | | |
|---|---|---|
| Dr. Joel Cramer | work phone | (402) 472-7533 |
| | cell phone | (402) 405-4345 |
| | home phone | (402) 291-9940 |
| Zachary Gillen | work phone | (402) 472-7738 |
| | cell phone | (214) 803-6979 |

The University of Nebraska-Lincoln wants to know about your research experiences. This 14 question, multiple-choice survey is anonymous. This Survey should be

completed after your participation in this research. Please complete this optional online survey at: http://bit.ly/UNLresearchfeedback.

APPENDIX C

**Young Child Verbal Assent Script**

"Would you like to be part of our project? We are asking because you play sports, and we want to see how you do! If you decide to be in our project we'll even pay you some money.

We're going to see how much you weigh, how tall you are, and how big your muscles are! To do this we'll have to measure your arms, legs, and tummy. We'll ask you to jump as high as you can. We'll also ask you to do a big push-up. Then we're going to ask you to do some leg exercises on an exercise machine. If you don't know how to do something we will help you.

We're going to use your scores to write papers and make projects for school. No one will be able to tell which scores are yours because we will put them in a group with everyone's scores without all of your names.

These tests will make you breathe hard and make you feel tired, but everything you will do is a lot like what you have done in PE class or at your sports practices. Does this sound like something you want to do if it's okay with your parents?"

APPENDIX D

University of Nebraska Lincoln

# Official Approval Letter for IRB project #17495 - Change Request Form

November 21, 2017

Joel Cramer
Department of Nutrition and Health Sciences
LEV 211, UNL, 685830806

Zachary Gillen
Department of Nutrition and Health Sciences
3139 N Hill Rd Apt 207 Lincoln, NE 68504

IRB Number: 20171017495EP
Project ID: 17495
Project Title: Changes in noninvasive, applied physiological laboratory measurements and field measurements of athletic performance in children and youth: Influences of growth and development

Dear Joel:

The Institutional Review Board for the Protection of Human Subjects has completed its review of the Request for Change in Protocol submitted to the IRB.

The change request form has been approved to include the following changes and procedures as described in the form:

1) Change of location to Ruth Leverton Hall
2) Change of testing time frame from 3 time points at 0, 6, and 12 months to 2 time points within a week
3) Removal of shuttle run, 20-yard dash, and L-cone drill from protocol
4) Payment to each participant $10 cash for each test visit ($20 total).

Date of Expedited review and approval: 11/16/2017

We wish to remind you that the principal investigator is responsible for reporting to this Board any of the following events within 48 hours of the event:
* Any serious event (including on-site and off-site adverse events, injuries, side effects, deaths, or other problems) which in the opinion of the local investigator was unanticipated, involved risk to subjects or others, and was possibly related to the research procedures;
* Any serious accidental or unintentional change to the IRB-approved protocol that involves risk or has the potential to recur;
* Any publication in the literature, safety monitoring report, interim result or other finding that indicates an unexpected change to the risk/benefit ratio of the research;
* Any breach in confidentiality or compromise in data privacy related to the subject or others; or
* Any complaint of a subject that indicates an unanticipated risk or that cannot be resolved by the research staff.

This letter constitutes official notification of the approval of the protocol change. You are therefore authorized to implement this change accordingly.

If you have any questions, please contact the IRB office at 402-472-6965.

Sincerely,

Rachel Wenzl, CIP
for the IRB