THE ASSOCIATION OF SPORT CONFIDENCE AND DROP VERTICAL JUMP PERFORMANCE FOLLOWING ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

By

Robin Alberta Goody

A thesis submitted to the Department of Kinesiology and Health Studies in conformity with the requirements for the degree of Master of Science

Queen’s University
Kingston, Ontario, Canada
August 2009

Copyright © Robin Alberta Goody, 2009
Abstract

Determining if an athlete, who has had Anterior Cruciate Ligament (ACL) surgery, is ready to return to sport is a difficult clinical decision, partially due to the lack of standardized evaluation protocols. Since there is a risk of re-injury post-surgery, medical teams need to be cautious. However, athletes who are perceived to be ready to return to sport do not necessarily do so. Some leave sport altogether while others return to a lower competition level. As psychological thoughts and emotions are relevant to athletes’ injury experiences, a psychological component, such as sport confidence, needs to be thoughtfully considered during the return to sport process. Our objectives were to develop the relationship between drop vertical jump (DVJ) performance and physical attributes in young healthy adults and to then apply this relationship to ACL participants. Another objective was to see if the relationship is improved by including confidence (determined from a survey). It was hypothesized that including confidence will predict the ACL participants’ DVJ performance more precisely.

Thirty-five participants were in the control group with thirteen participants in the ACL group. All were recreationally active and all had the following anthropometric and performance measurements recorded: height, weight, calf and thigh girth, knee angle, leg dominance, percent body fat, skeletal muscle mass, anaerobic power, balance, and drop vertical jump height. The ACL group also completed a confidence survey. Regression analyses were performed.

The results showed that anaerobic power and relative skeletal muscle mass were significant predictors of DVJ performance; however, DVJ performance could not be predicted precisely. The analysis was also carried out by gender. No significant predictors for male’s DVJ performance were found while the significant predictors for female’s DVJ performance were weight, power and knee extension angle. Once again, DVJ performance could not be precisely predicted. On the other hand, results showed that power could be more precisely predicted by body weight than could DVJ performance.
Acknowledgements

It is a pleasure to thank all the people who supported me throughout the journey of my Masters. If it were not for the fantastic support network of my family and friends this thesis would not have been completed.

First of all, I would like to express my sincere gratitude to Dr. Pat Costigan, my thesis supervisor, for his constant enthusiasm and guidance. Throughout the two years he provided encouragement and insight that helped to keep me motivated to complete this thesis, even when I decided to push everything to the last semester. I think we made a great team tackling this project and I would have been lost without him.

Sincere thanks are extended to the members of my advisory committee, Dr. Joan Stevenson and Dr. Davide Bardana. The devotion of their time and the many valuable suggestions made helped improve this thesis. It was also a great learning experience to be in the operating room for an ACL reconstruction.

Additionally, I would like to thank all the participants who volunteered their time to partake in my study. Although some of you had way more fun than what you thought you would with some of the tests! Without your participation, this thesis would be non-existent.

I am extremely thankful for all the support and encouragements from my friends. It was you who saw me through the tough times and celebrated with me during the better times. You never let me down. Thank you for all the emotional support, camaraderie, entertainment, and caring you provided.

I would like to thank my friends in Kingston: Melissa Dermody, Jenn Tomason, Bryce Donald and Andrea Andrecyk, who all played a role in getting me through the past two years. Mel, you have been a wonderful housemate and I have thoroughly enjoyed our time living together. I would have been a stress case if it was not for our fun activities of painting and movies! Jenn, you
have offered great insight and motivated me over the years and I don’t know what I would do without our daily lunch breaks. Bryce, you were the one who always took my mind off of all the school related stress so that we could just sit back and laugh. Andrea, you always brought a smile to my face followed by a good laugh with solid advice.

I would also like to thank my 21B Nelson girls: Laura Chesher, Laurin Archer and Lois Johnson. The three of you have definitely been a huge part of my support network since first year in undergrad. I can also rely on the three of you for a long phone conversation full of laughs and advice. I am so appreciative of the friendship that we have and although we are spread out over the province (or a couple of provinces) I hope we all remain close. I look forward to what the future holds for us.

Additionally, I would like to thank my cousin and best friend, Kerry Simpson. Kerry, you have always been there for me no matter what time of day. You always know how to pick me up when I am down, calm me down when I stressed, and talk some sense into me when I go a little crazy. We have had a lot of good times over the years and I look forward to the more good times down the road.

Finally, I wish to thank my family. To my brother and sister, who have always believed in me and who let me pick a fight here and there. And to my parents, who raised me, supported me, taught me and loved me. I would not be where I am today without your constant financial, emotional and physical support. I love you guys!
# Table of Contents

Abstract  .......................................................................................................................... lii
Acknowledgements....................................................................................................... iii
Table of Contents ........................................................................................................ v
List of Figures................................................................................................................ vii
List of Tables ................................................................................................................ ix

Chapter 1 Introduction ................................................................................................... 1

Chapter 2 Literature Review .......................................................................................... 5
  2.1 Mechanism of Injury ............................................................................................... 7
  2.2 Reconstructive Surgery ......................................................................................... 12
  2.3 Performance Post-Surgery ................................................................................... 12
  2.4 Return to Sport ....................................................................................................... 15

Chapter 3 Objectives ..................................................................................................... 20

Chapter 4 Methods ....................................................................................................... 21
  4.1 Participants ............................................................................................................ 21
  4.2 Experimental Protocol .......................................................................................... 22
    4.2.1 Anaerobic Power Test ..................................................................................... 22
    4.2.2 Balance Test .................................................................................................... 25
    4.2.3 Measurements ................................................................................................. 26
    Calf & Thigh Girth .................................................................................................... 26
    Knee Extension Angle ............................................................................................... 26
    Leg Dominance ......................................................................................................... 26
    Height, Weight, Percent Body Fat and Skeletal Muscle Mass ................................. 26
    4.2.4 Drop Vertical Jump (DVJ) .............................................................................. 29
    4.2.5 Confidence Survey ......................................................................................... 32
  4.3 Statistical Analysis ................................................................................................. 32

Chapter 5 Results ......................................................................................................... 33

Chapter 6 Discussion .................................................................................................... 42
  6.1 General Discussion ............................................................................................... 42
  6.2 Clinical Relevance ................................................................................................. 49
  6.3 Limitations ............................................................................................................. 50
  6.4 Conclusions .......................................................................................................... 51

v
List of Figures

Chapter 2
Literature Review

Figure 2.1: a) Anterior view of the right knee joint, showing the ACL in the red circle. b) Superior view of the right tibia, showing the ACL in the red circle (adapted from Gray & Lewis, 1918)........6

Figure 2.2: Motion sequence of an ACL injury, caused by a sharp deceleration prior to a change in direction (adapted from Boden et al., 2000).................................................................9

Figure 2.3: Motion sequence of an ACL injury, caused by a single-leg landing with valgus collapse (adapted from Boden et al., 2000).........................................................................................10

Chapter 4
Methods

Figure 4.1: A participant performing the anaerobic power test: a) posterior view and b) sagittal view. The ribbon switches are circled and labeled.................................................................24

Figure 4.2: A participant performing the balance test.................................................................25

Figure 4.3: A participant standing on the bioelectrical impedance analyzer.................................27

Figure 4.4: The Optotak camera..................................................................................................30

Figure 4.5: A drop vertical jump: a) standing on the box with the left leg lifted prior to dropping; b) landing after the drop; c) jumping as high as possible; d) landing after the jump.................................31

Chapter 5
Results

Figure 5.1: The relationship between maximum DVJ height (mm) and power (kg m/s) for both the control group and the ACL group..........................................................................................36

Figure 5.2: The relationship between maximum DVJ height (mm) and relative skeletal muscle mass (%) for both the control group and the ACL group........................................................................37
Appendices

Figure G1: Image of the interface of the custom LabView program used as the timer for the anaerobic power test, where the timer started and stopped when contact was made with the first and second switch, respectively................................................................. 86

Figure G2: The block diagram of the custom LabView program, used as the timer for the anaerobic power test............................................................................................................................................................................. 87

Figure J1: Flow chart of Matlab functions used to process the DVJs................................................................. 93
List of Tables

Chapter 5

Results

Table 5.1: Three regression models predicting maximum DVJ height (mm). Model 1 is the coefficients for variables selected for the control group based on stepwise selection with the model as follows: DVJ height = constant + %skeletal muscle + power; where % skeletal muscle is the relative skeletal muscle mass (%) and power is the outcome of the anaerobic power test (kg m/s) (n=35). Model 2 is the coefficients determined for the variables selected from the control group but applied to the ACL group (n=13). Model 3 is the same as Model 2 except survey, the percentage scored on the confidence survey, is added (n=13) ........................................................................................................ 34

Table 5.2: The regression model for predicting the maximum height jumped during the DVJ task, DVJ height (mm) in females. Model 4 is the coefficients for variables selected from the control group’s females based on stepwise selection with the model format as follows: DVJ height = constant + weight + power + knee angle; where weight is the participants’ body mass (kg), power is the output determined by the anaerobic power test (kg m/s), and knee angle is the amount of end range knee extension (degrees) (n=17) ........................................................................................................ 38

Table 5.3: Five regression models for predicting power (kg m/s) in the females and males of the control group separately as well as in the whole control group and the whole ACL group. Model 5 is the coefficients for variables selected from the control group’s females based on stepwise selection with the model format as follows: power = weight; where weight is the participants’ body mass (kg) (n=17). Model 6 is the coefficients for variables selected for the control group’s males based on stepwise selection (n=18). Model 7 is the coefficients for the same variable from Model 5 and Model 6 but applied to the whole control group (n=35). Model 8 is the same as Model 7 but applied to the whole ACL group (n=13). Model 9 is the same as Model 8 except survey, the percentage scored on the confidence survey, was added as another variable (n=13). ........................................................................................................ 40
Appendices

Table A1: Control participants’ results for gender, age (years), height (m), mass (kg), leg dominancy, average calf girth (mm), average thigh girth (mm), average knee angle (°), power (kg m/s), balance (s), relative body fat (%), body fat mass (kg), relative skeletal muscle (%), skeletal muscle mass (kg), and DVJ height displacement (mm). ................................................................. 68

Table A2: ACL participants’ results for gender, age (years), height (m), mass (kg), leg dominancy, average calf girth (mm), average thigh girth (mm), average knee angle (°), power (kg m/s), balance (s), relative body fat (%), body fat mass (kg), relative skeletal muscle (%), skeletal muscle mass (kg), DVJ height displacement (mm) and survey score (%). ................................................................. 70

Table F1: ACL subjects’ information including date of injury, date of surgery, type of graft used, leg operated on, number of months of rehabilitation, clearance for sports participation and current sports status. ........................................................................................................ 84

Table H1: Paired t-test and correlation results for the control group with comparisons between left and right sides for calf girth, thigh girth and knee angle. ........................................................................................................ 89

Table H2: Paired t-test and correlation results for the ACL group with comparisons between left and right sides for calf girth, thigh girth and knee angle. ........................................................................................................ 89

Table I1: Paired t-test and correlation results for the control group’s males with comparisons between the Tanita BC-418 equation and the equation developed by Sun and colleagues (2003). ........................................................................................................ 91

Table I2: Paired t-test and correlation results for the control group’s females with comparisons between the Tanita BC-418 equation and the equation developed by Sun and colleagues (2003). ........................................................................................................ 91

Table L1: Multicollinearity statistics, tolerance and variance inflation factor (VIF) for models 1-9. 106

Table M1: Actual, predicted and residual values for the ACL group using Model 8: power = -41.07 + 1.89weight, and Model 9: power = -54.48 + 1.78weight +0.33survey. ........................................................................................................ 108

Table N1: Pearson correlation coefficients for the control group’s data for the following variables: weight, knee angle, power, % body fat, body fat mass, % skeletal muscle, skeletal muscle mass, and DVJ height. * denotes significance with p<0.05. ........................................................................................................ 110
Table N2: Pearson correlation coefficients for the ACL group’s data for the following variables: weight, knee angle, power, % body fat, body fat mass, % skeletal muscle, skeletal muscle mass, survey and DVJ height. * denotes significance with p<0.05. 111

Table N3: Pearson correlation coefficients for the control group females’ data for the following variables: weight, knee angle, power, % body fat, body fat mass, % skeletal muscle, skeletal muscle mass, and DVJ height. * denotes significance with p<0.05. 112

Table N4: Pearson correlation coefficients for the control group males’ data for the following variables: weight, knee angle, power, % body fat, body fat mass, % skeletal muscle, skeletal muscle mass, and DVJ height. * denotes significance with p<0.05. 113
Chapter 1

Introduction

For athletes, the Anterior Cruciate Ligament (ACL) is one of the most commonly torn knee ligaments (Boden, Griffin, & Garrett, 2000; Herrington, Wrapson, Matthews, & Matthews, 2005; Morrey, Stuart, Smith, & Wiese-Bjornstal, 1999; Myklebust & Bahr, 2005). Typically, ACL injuries are treated with reconstructive surgery using either a graft of the patellar tendon or the hamstrings tendon, commonly followed by an accelerated rehabilitation program that includes immediate range of motion and weight bearing exercises with the athlete returning to sports within four to six months (Kvist, Ek, Sporrstedt, & Good, 2005). The goal of surgery and rehabilitation is to enable the athlete to return to their full functional level prior to the injury and then resume their sport. However, differences in performance post-surgery between ACL reconstructed participants and healthy controls have been reported during the high functioning tasks common in many sports, such as jumping and landing (Decker, Torry, Noonan, Riviere, & Sterett, 2002; Ernst, Saliba, Diduch, Hurwitz, & Ball, 2000; Paterno, Ford, Myer, Heyl, & Hewett, 2007). Additionally, researchers have found that 12% of ACL reconstructed athletes suffered a repeat ACL injury (Salmon, Russell, Musgrove, Pinczewski, & Refshauge, 2005). It is possible that the recognized differences are, in part, responsible for the repeated injuries, therefore, it is critical to investigate thoroughly these differences in performance when evaluating if an athlete is ready to return to sport.

There is limited research on jumping and landing performance in athletes who have had ACL reconstruction surgery. The few studies that do exist have demonstrated differences in the tasks post-surgery when comparing ACL participants to healthy participants (Decker et al., 2002; Ernst et al., 2000; Paterno et al., 2007). ACL athletes’ performance during jumping and landing has been examined in two studies where results from both showed a decreased knee extensor moment during task execution when compared to the healthy participants and when compared to their
uninjured leg (Decker et al., 2002; Ernst et al., 2000). During jumping these athletes increased the moments at the hip and ankle (Ernst et al., 2000) while during landing they reduced the time to peak force (decreased the loading rate) to reduce the knee extensor moment (Decker et al., 2002).

Additionally, researchers have examined limb asymmetries in an ACL group during a task that involves both jumping and landing, a drop vertical jump (DVJ), where one drops off a box and immediately jumps as high as possible. Results demonstrated that the ACL group had side-to-side differences during both the landing and take-off phase of the DVJ whereas the control group exhibited no differences. More specifically, during the landing phase the vertical ground reaction force and loading rate for the ACL group was higher in their uninvolved limb than their involved limb and higher than both limbs of the control group. Also, during the take-off phase the vertical ground reaction force for the ACL group was lower in their involved limb than their uninvolved limb and both limbs of the control group (Paterno et al., 2007). Clearly, the uninvolved limb is compensating to allow a reduced load on the involved limb. These studies demonstrate that differences in performance are present during jumping and landing, specifically during a DVJ task, post ACL surgery. As jumping and landing are both tasks used in a wide range of sporting activities it is imperative to further understand these differences between the ACL and healthy participants.

The vertical jump test is often used to determine an athlete’s physical ability to jump, a fundamental skill in many sports (Davis, Briscoe, Markowski, Saville, & Taylor, 2003). Researchers have examined several factors that influence vertical jump performance and the results have varied. For example, when evaluating lower limb strength and vertical jump performance, Blackburn and Morrissey (1998) found a positive correlation, but Young, Wilson and Byrne (1999) found no correlation. On the other hand, Davis and colleagues (2003) investigated many physical characteristics that may contribute to an athlete’s vertical jump performance and found that the best linear regression model to predict vertical jump height included percent body fat, anaerobic power test time, balance test time, age and right calf girth. These factors should be considered when
evaluating vertical jump performance. This suggests that by measuring an athlete’s physical characteristics you can predict their vertical jump performance. If such a relationship were strong, you could compare an athlete’s predicted and actual performance to determine if their current performance was within the normal range and if they are ready to return to full sport participation. This might be a very useful evaluation following ACL surgery.

Presently, no research has identified the factors that influence or predict performance during a DVJ task. Since differences have been found during the DVJ in an ACL population it would be interesting to investigate the factors that may be associated with and predict performance of a DVJ and to compare them with a healthy population. Possibly evaluating these physical characteristics and comparing predicted and actual DVJ performance could aid medical teams in determining if an ACL athlete is ready to return to sport.

Although many ACL reconstruction surgeries are successful not all athletes return to their previous level of sport. Athletes give a number of reasons for not returning to sport including changes in lifestyle, decreased confidence and fear of re-injury (Cooley, Deffner & Rosenbery 2001; Jennings, Rasquinha & Dowd 2003; Kvist et al., 2005). Recently, the psychological impact of an injury to an athlete has merited much attention. For example, the fear of re-injury affects the athletes’ decisions to return to sport and decreases their level of participation (Kvist et al., 2005; Tripp et al., 2007). Also, it has been suggested that for athletes returning to sport following an injury their sport confidence, defined as their confidence in their ability to perform well at their sport, is critical (Evans, Hardy & Fleming 2000; Quinn & Fallon 1999; Webster, Feller & Lambros 2008). To evaluate sport confidence the ACL-Return to Sport after Injury scale has been developed and validated (Webster, Feller, & Lambros, 2008). The scale has twelve questions that address an athlete’s emotion, confidence in performance and risk appraisal, to measure the psychological impact of returning to sport specifically following ACL surgery (Webster et al., 2008). However, to date the scale has not been applied to an ACL population to evaluate their psychological response to
returning to sport. This scale could be used to further investigate athletes’ confidence following ACL surgery and explain why some athletes do not resume sport.

Confidence is crucial to injured athletes returning to sport and, consequently, should be part of the medical teams’ evaluations when trying to determine if an athlete is ready to return to sport. The decision for an athlete to return to sport is imperative for the athletes’ safety and, therefore, the decision should be based on a set of standardized objective criteria that includes sport confidence. Additionally, kinematic and kinetic differences between ACL participants and healthy participants have been identified in jumping and landing, demanding tasks required in sports. Currently, there are physical attributes that predict vertical jumping performance and these attributes may be similar to those that predict DVJ performance. As a result, a set of standardized objective criteria should be developed that includes both sport confidence and the physical attributes that predict DVJ performance. This set of criteria can then be used by medical teams to evaluate if an athlete is ready to return to sport by comparing the predicted DVJ performance to the athlete’s actual performance.
Chapter 2

Literature Review

The ACL (Figure 2.1) is one of the knee’s most important structures. It provides stability to the joint preventing the femur from moving posteriorly, it stabilizes the tibia against excessive internal rotation and it serves as a secondary restraint for valgus and varus stress (Arnheim & Prentice, 1992). An estimated 100,000 ACLs are torn each year, 70% of which occur during athletic activities (Senter & Hame, 2006). Injury to the ACL can lead to degradation of knee joint cartilage, loss of joint stability and reduced joint mobility. This loss of stability and mobility can significantly reduce a person’s activity level as well as their quality of life. Fortunately due to medical advances, surgical reconstruction of the ACL has become a relatively routine procedure (Olsen et al, 2004). With the combination of rehabilitation and sport specific exercises following surgery, surgeons hope that athletes will re-establish a fully functional knee joint, ideally returning to their previous level of sport. Many surgical repairs are successful, but some athletes do not return to their sport, some do not return to their previous competitive level, while others leave sport altogether. At present, there is no clear reason for the difference between complete success and abject failure.
Figure 2.1: a) Anterior view of the right knee joint, showing the ACL in the red circle. b) Superior view of the right tibia, showing the ACL in the red circle (adapted from Gray & Lewis, 1918).
2.1 Mechanism of Injury

Although ACL injuries are quite common, it is difficult to determine an exact mechanism of injury. Researchers have used questionnaires and observational video analyses to identify mechanisms and activities during the time of an ACL tear (Boden et al., 2000; Cochrane, Lloyd, Buttfield, Seward, & McGivern, 2007; Fauno & Jakobsen, 2006; Ferretti, Papandrea, & Conteduca, 1992; Olsen, Myklebust, Engebretsen, Holme, & Bahr, 2003; Olsen, Myklebust, Engebretsen, & Bahr, 2004). Furthermore, researchers have been examining specific loads and combination loads that stress the ACL and, therefore, put it at risk of injury (Arms, Pope, & Johnson, 1984; Berns, Hull, & Patterson, 1992; Draganich & Vahey, 1990; Durselen, Claes, & Kiefer, 1995; Gabriel, Wong, Woo, Yagi, & Debks, 2004; Kanamori et al., 2000; Kanamori et al., 2002; Li et al., 1999; Li et al., 2004; Markolf et al., 1995; Markolf, O’Neill, Jackson, & McAllister, 2004; Renstrom, Arms, Stanwyck, Johnson, & Pope, 1986; Sakane et al., 1999; Woo et al., 1998). To develop effective prevention methods it is imperative to understand the mechanisms and forces that result in ACL injuries.

Questioning athletes who have suffered an ACL injury helps determine the mechanisms of injury. Research that asks athletes who have suffered an ACL tear to describe what was happening during the injury shows that the majority of athletes report a noncontact mechanism of injury (Boden et al., 2000; Fauno & Jakobsen, 2006; Ferretti et al., 1992; Olsen et al., 2003). In addition, the most common noncontact mechanism, ranging from 51% to 75% of all noncontact injuries, was deceleration with or without change in direction (Figure 2.2) (Boden et al., 2000; Fauno & Jakobsen, 2006; Olsen et al., 2003). This deceleration maneuver has the hip extended, the knee near full extension with either a valgus collapse at the knee, the tibia internally rotating, or valgus collapse and internal tibial rotation. An example of this motion is when a soccer player approaches an opposing player, pivots and changes direction to move around the player. The second most common noncontact mechanism was landing after a jump (Figure 2.3), with percentages ranging from 16% to 43% of all noncontact injuries (Boden et al., 2000; Fauno & Jakobsen, 2006; Olsen et al., 2003). This
landing maneuver consists of the quadriceps fully contracted, the knee near full extension and a valgus collapse of the knee. This motion can be seen in basketball when a player is landing after a lay-up. Thus, research employing retrospective questionnaires post-ACL injury has identified the two most common noncontact injury mechanisms; a noncontact, deceleration with or without a change in direction and a landing after a jump.

In addition to retrospective questionnaires, video analyses are used to uncover ACL injury mechanisms. Analysis of videos taken when ACL injuries occur show that the majority of injuries were from noncontact mechanisms (Boden et al., 2000; Cochrane et al., 2007; Olsen et al., 2004). This agrees with the findings from the retrospective questionnaires. The video analyses also determined that the most common noncontact mechanism, with percentages of all noncontact injuries ranging from 37% to 77%, was deceleration with or without change in direction, which again agrees with the questionnaire results (Boden et al., 2000; Cochrane et al., 2007; Olsen et al., 2004). Video analyses confirmed questionnaire findings again by reporting that the second most common mechanism was landing after a jump, with percentages of all noncontact injuries ranging from 23% to 33% (Boden et al., 2000; Cochrane et al., 2007; Olsen et al., 2004). Results from video analyses agree with questionnaire results that the two most common ACL injury mechanisms are a noncontact, deceleration with or without a change in direction and landing after a jump.

Researchers have also applied external loads to the knee in vitro to investigate the loading patterns of the ACL. This research may not uncover the direct mechanisms of ACL injury, but suggests possible external loads that stress the ACL and put it at risk of damage. ACL tensile forces have been measured with the application of an external anterior shear force, excessive quadriceps contractions and with quadriceps and hamstrings co-contractions (Arms et al., 1984; Draganich & Vahey, 1990; Durselen et al., 1995; Li et al., 1999; Li et al., 2004; Markolf et al., 1995; Markolf et al., 2004; Renstrom et al., 1986; Sakane et al., 1999; Woo et al., 1998). When an anterior shear force is applied to the tibia with the knee near full extension (less than 30° of knee flexion) the tensile force
Figure 2.2: Motion sequence of an ACL injury, caused by a sharp deceleration prior to a change in direction (adapted from Boden et al., 2000).
Figure 2.3: Motion sequence of an ACL injury, caused by a single-leg landing with valgus collapse (adapted from Boden et al., 2000).
on the ACL is of similar magnitude to the applied force (Sakane et al., 1999; Woo et al., 1998). Conversely, when the knee is flexed more than 60°, the tensile force on the ACL is less than the applied force (Sakane et al., 1999; Woo et al., 1998). These findings indicate that the ACL is under greater stress, therefore at more risk, from anterior forces when the knee is near full extension.

These external forces can be altered by internal muscle forces. For example, the tensile force in the ACL is increased with quadriceps contractions when they are unopposed by the hamstrings and this effect is greater during shallow knee flexion (less than 40-60°) than when the knee is flexed more than 45-60° (Arms et al., 1984; Draganich & Vahey, 1990; Durselen et al., 1995; Li et al., 1999; Li et al., 2004; Markolf et al., 1995; Markolf et al., 2004; Renstrom et al., 1986). However, when the hamstrings are contracted, there is a reduction in the ACL tensile force suggesting that the hamstrings provide a protective mechanism, and the reduction of the tensile force in the ACL increases as the knee flexes (Draganich & Vahey, 1990; Li et al., 1999; Li et al., 2004; Markolf et al., 2004; Renstrom et al., 1986). Thus, the ACL is most vulnerable with an anterior shear force or excessive quadriceps contraction when the knee is near full extension.

Anterior forces or the force applied by the quadriceps can be augmented by forces that twist the tibia. When an anterior shear force or a quadriceps force is combined with a rotational moment about the knee, the loads on the ACL are increased. This increase is greater with an internal rotation moment than with an external rotation moment and, again, higher ACL loads are observed near full knee extension (Arms et al., 1984; Berns et al., 1992; Markolf et al., 1995; Markolf et al., 2004). This implies that the ACL is at a higher risk of injury when there is an internal rotation moment applied with either a quadriceps force or an anterior shear force. ACL tensile forces are also increased with a combined load of a valgus moment and a knee internal rotation moment (Gabriel et al., 2004; Kanamori et al., 2000; Kanamori et al., 2002). This further indicates that the risk of ACL injury is increased when there is a combined internal rotation and valgus moment as well as quadriceps contraction.
2.2 Reconstructive Surgery

Presently, the majority of surgeons perform ACL reconstruction using an arthroscopically assisted technique with an autogenous graft (Herrington et al., 2005; Jansson, Linko, Sandelin, & Harilainen, 2003). The two most popular autogenous grafts are the bone-patellar tendon-bone graft and the semitendinosus and gracilis tendons graft (also referred to as hamstring tendon graft) (Aune, Holm, Risberg, Jensen, & Steen, 2001; Beard, Anderson, Davies, Price, & Dodd, 2001; Herrington et al., 2005; Jansson et al., 2003). There is significant controversy over the choice of the best graft for successful ACL surgery. Many studies have used controlled, randomized trials to directly compare the two graft choices using a variety of outcome measures. These measures include, but are not limited to, return to pre-injury level of activity, pain, muscle strength, knee stability, range of motion and the International Knee Committee Documentation survey, which evaluates overall knee function (Anderson, Snyder, & Lipscomb, 2001; Aune et al., 2001; Beard et al., 2001; Carter & Edinger, 1999; Ejerhed, Kartus, Sernert, Kohler, & Karlsson, 2003; Eriksson et al., 2001; Eriksson, Anderberg, Hamberg, Olerud, & Wredmark, 2001; Feller, Webster, & Gavin, 2001; Jansson et al., 2003; Shaieb, Kan, Chang, Marumoto, & Richardson, 2002; Webster, Feller, & Hameister, 2001). Overall, research indicates that there are no significant differences between the patellar tendon grafts and hamstring tendon grafts in terms of the outcome measures used and that both grafts are successful at improving athletes’ performance post-surgery and post-rehabilitation (Anderson et al., 2001; Aune et al., 2001; Beard et al., 2001; Carter & Edinger, 1999; Ejerhed et al., 2003; Eriksson et al., 2001; Eriksson, Anderberg, Hamberg, Olerud et al., 2001; Feller et al., 2001; Shaieb et al., 2002; Webster et al., 2001).

2.3 Performance Post-Surgery

As the majority of ACL injuries are followed by surgery, it is imperative to thoroughly understand the effects surgery can have on the athlete’s lower limb biomechanics. Numerous studies have identified kinetic and kinematic differences between ACL reconstructed participants and healthy
participants that are present during simple activities of daily living such as walking and stair climbing (Gokeler, Schmalz, Knopf, Freiwald, & Blumentritt, 2003; Hooper et al., 2002; Knoll, Kocsis, & Kiss, 2004; Kowalk, Duncan, & McCue, 1997; Kurz, Stergiou, Buzzi, & Georgoulis, 2005); as well as during more demanding tasks, such as jumping and landing (Decker et al., 2002; Ernst et al., 2000; Paterno et al., 2007).

Several post-surgical differences during walking (following ACL reconstruction) have been discovered (Gokeler et al., 2003; Knoll et al., 2004; Kurz et al., 2005). For example, ten months after ACL reconstructive surgery participants exhibit altered relative phase dynamics, which quantify interjoint coordination, at both the ankle (foot-shank) and the knee (shank-thigh) during walking and running (Kurz et al., 2005). In addition, gait research has found that ACL participants showed higher angular differences between maximal flexion and maximal extension during the stance phase, known as the flexion-extension deficit, which is caused mainly by an extension deficit during midstance (Gokeler et al., 2003). While there are a range of changes after ACL surgery, gait patterns do not normalize for at least eight months (Knoll et al., 2004). In addition to changes in level walking, postsurgical variations during stair climbing have also been reported (Hooper et al., 2002; Kowalk et al., 1997). Hopper and colleagues (2002) described asymmetrical patterns, with decreased external flexion torque and decreased power, at the injured knee during stair climbing in ACL participants up to one year post-surgery. Similarly, Kowalk and colleagues (1997) detected asymmetrical patterns with decreased moment, power and work at the reconstructed knee during stair climbing six months after surgery. Many studies have described differences post ACL reconstructive surgery when comparing ACL participants to a healthy control group in activities of daily living such as walking and stair climbing.

In addition to analyzing differences in activities of daily living following ACL reconstructive surgery, studies have also investigated differences in jumping and landing. Jumping and landing, commonly used in athletic competitions, are highly demanding tasks that require large quadriceps and
Moreover, since research has identified landing following a jump as a possible ACL injury mechanism, it is crucial to understand the deficits in these tasks following injury. Unfortunately, there is limited research on jumping and landing irregularities; the few studies that do exist have revealed differences in jumping and landing post ACL surgery (Decker et al., 2002; Ernst et al., 2000; Paterno et al., 2007).

Studies examining differences during jumping and landing tasks post ACL surgery found a decreased knee extensor moment during the take-off phase and landing phase (Decker et al., 2002; Ernst et al., 2000). Ernst and colleagues (2000) examined a single-leg vertical jump task ten months after ACL surgery and found that the knee extension moment of the injured leg to be lower than on the contralateral leg and lower than both legs of the control group. However, the total lower limb extensor moment (the sum of the hip, knee and ankle moments) was not different between legs or in comparison to the control group. Similarly, Decker and colleagues (2002) found a reduced knee extensor moment during landing in the ACL reconstructed group, all of whom had had ACL reconstructive surgery at least one year prior to testing. Additionally, these studies suggested strategies may have been used to reduce the knee extensor moment. In the single-leg jump study the knee moment was reduced while the summated extension moment (hip + knee + ankle) was the same in both legs suggesting that the hip and ankle moments were increased to compensate for the knee extensor moment deficit (Ernst et al., 2000). In the landing performance study, a load reducing strategy may have been employed since they reported a reduced loading rate to peak force in addition to reduced hip extensor moments and power, reduced knee extensor power, and less energy absorption from the hip extensors with more absorbed from the ankle plantarflexors (Decker et al., 2002). Both studies have presented variations in the mechanics used during jumping and landing indicating possible strategies to reduce the moment at the injured knee joint.

Limb asymmetries during a DVJ task, where one drops off a box and immediately jumps as high as possible, have been studied in a control group and an ACL group. The ACL group was, on
average, 27 months post-surgery and had been allowed to return to sport. Results demonstrated that the ACL group had side-to-side differences during both the landing and take-off phase of the DVJ whereas the control group exhibited no differences. More specifically, the vertical ground reaction force and loading rate during the landing phase were higher in the uninvolved limb in the ACL group than the involved limb as well as both limbs of the control group. Also, the vertical ground reaction force during the take-off phase was lower in the involved limb in the ACL group than the uninvolved limb and both limbs of the control group (Paterno et al., 2007). These studies demonstrate that differences in performance are present during jumping and landing, specifically during a DVJ task, post ACL surgery. The presence of these differences may pose a risk of injury or re-injury to the contralateral leg, as landing from a jump has been identified as an ACL injury mechanism.

2.4 Return to Sport

Over the years, the rehabilitation process following ACL reconstruction surgery has changed from a conservative program that delays range of motion exercises and weight bearing and has athletes returning to sport within nine to twelve months to an accelerated program implementing range of motion exercises and weight bearing immediately and has athletes returning to sport within four to six months (Kvist, 2004). Two recent review articles, by Cascio and colleagues (2004) and Kvist and colleagues (2004), both found an average return to sports time of seven months using the accelerated rehabilitation programs. Presently, medical teams use anterior-posterior tibiofemoral motion determined by clinical evaluation (Lachman’s test) or use of an arthrometer, post surgical timeline and subjective opinions in making the decision to return an athlete to play (Myer, Paterno, Ford, Quatman, & Hewett, 2006). As one of the main goals of ACL reconstruction is for athletes to return to their previous level of sport, an indication of a successful rehabilitation program is when athletes are released to unrestricted sporting activities, thus, the current trend is to release athletes as early as possible. But, if an athlete returns to sport without achieving functional stability there may
be a risk of re-injury (Myer et al., 2006). Researchers found that at five years post ACL surgery 12% of athletes suffered a repeat ACL injury, with half of those occurring in the contralateral knee.

Research has also shown that the risk of sustaining a rupture to a graft was the highest in the twelve months following surgery (Salmon et al., 2005). Although the current trend is an accelerated rehabilitation process, precautions must be taken to ensure the athlete is ready to return to sport without the risk of re-injury.

The decision to allow an athlete to return to sport is challenging and has been subject of much debate. Currently, there is no standardized, objective protocol that is applied when evaluating if an athlete is ready to return to sport. Numerous studies report that athletes have been released to unrestricted sports as early as three months (Gobbi, Diara, Mahajan, Zanazzo, & Tuy, 2002; Howell & Deutsch, 1999; M. Marcacci et al., 1998; M. Marcacci et al., 2003; Muellner, Alacamioglu, Nikolic, & Schabus, 1998; Sauter, van Haeff, van der Lubbe, & Eggenaald, 1998; Webster et al., 2001) and as late as six to twelve months (Bak, Jorgensen, Ekstrand, & Scavenius, 2001; Deehan, Salmon, Webb, Davies, & Pinczewski, 2000; M. Hamada et al., 2000; M. Hamada et al., 2001; Jansson et al., 2003; Jorgensen, Bak, Ekstrand, & Scavenius, 2001; Panni, Milano, Tartarone, Demontis, & Fabbriciani, 2001; Webb, Corry, Clingeleffer, & Pinczewski, 1998). However, not all athletes who are given consent to return to sport actually return to their previous activity level. Follow-up studies reported 25-59% of ACL athletes did not return to their previous activity levels two to eight years following surgery (Aglietti, Buzzi, Giron, Simeone, & Zaccherotti, 1997; Bak et al., 2001; Cooley, Deffner, & Rosenberg, 2001; Corry, Webb, Clingeleffer, & Pinczewski, 1999; Feller & Webster, 2003; Gobbi, Tuy, Mahajan, & Panuncialman, 2003; Kvist et al., 2005; Myklebust & Bahr, 2005; Patel, Sam Church, & Hall, 2000; Siegel & Barber-Westin, 1998). There could be many possible reasons for athletes not returning to their previous sporting levels and attention should be directed at identifying these reasons.
Currently, there is a lack of research as to why athletes who are given consent to return to sport do not actually return to their previous activity levels. One reason, knee related problems, has been reported by 19-35% of those who did not return to sport, however, the exact nature of the problem was not specified (Bak et al., 2001; Kvist et al., 2005; Siegel & Barber-Westin, 1998). Furthermore, some literature has identified other reasons that may be indirectly related to the athletes' knee, such as family and job constraints, or directly related to the athletes' knee, such as decreased confidence and fear of re-injury (Cooley et al., 2001; Jennings, Rasquinha, & Dowd, 2003; Kvist et al., 2005). Kvist and colleagues (2005) reported that of the athletes who did not return to their previous activity levels, 24% did not return because of fear of re-injury. An athlete not returning to sport because of decreased confidence or fear of re-injury introduces a psychological component that merits attention.

In recent years, there has been a slight increase in research focused on athlete’s psychological response to serious injuries and the lengthy process of rehabilitation. Wiese-Bjornstal and colleagues (1998) have taken previous models based on psychological response to sport injury and proposed an integrated psychological model, which includes cognitive, emotional and behaviour responses. The cognitive response refers to an athlete’s self-perceptions and includes items such as self-esteem, self-efficacy, and self-confidence (Wiese-Bjornstal et al., 1998). The model also includes a dynamic section, where the responses may change over time from post-injury to post-surgery and to rehabilitation completion (Wiese-Bjornstal et al., 1998). Furthermore, the model illustrates that the three responses, cognitive, emotional and behavioural, all play a role in the recovery outcomes both physically and psychosocially (Wiese-Bjornstal et al., 1998). This model provides a foundation that may aid researchers in the recognition that athlete’s injury experiences encompass not only a physical perspective but psychological and social perspectives as well.

Presently, some literature has addressed psychological components that are related to athletes’ injury experiences. More specifically, Kvist and colleagues (2005) found that fear of re-
injury plays a vital role in ACL athletes’ decisions to return to sport and must be considered during the rehabilitation and evaluation of athletes. Similarly, Tripp and colleagues (2007) reported that decreased levels of participation were associated with increased levels of fear of re-injury in ACL reconstructed athletes. Moreover, results demonstrated that ACL athletes with greater negative mood had lower confidence in their sporting abilities (Tripp et al., 2007). Therefore, clinicians need to devote attention to athletes’ psychological responses that may be present during the recovery from ACL surgery.

It has been suggested that the specific psychological component, sport confidence, is essential for success among athletes who have sustained a serious injury and are returning to competitive sport (Evans, Hardy, & Fleming, 2000; Quinn & Fallon, 1999). According to Webster and colleagues (2008) sport confidence can be defined as the athlete’s confidence in their ability to perform well at his/her sport and specifically after ACL reconstruction the athlete’s confidence in his/her knee function (Webster et al., 2008). As confidence is vital to an injured athletes’ decisions in returning to sport it subsequently merits attention from medical teams. Medical teams should thoroughly evaluate and take into account athletes’ confidence during the rehabilitation process following ACL surgery as well as when it comes time to make the fundamental decision: is an athlete ready to return to sport?

Determining if an athlete, who has had ACL surgery, is ready to return to sport is a difficult decision for clinicians. It may be because of the lack of standardized protocols for evaluating if an athlete is indeed ready. Since there is a risk of re-injury post-surgery, medical teams need to be cautious. On the other hand athletes, who are perceived to be ready to return to sport, do not necessarily do so. Some athletes leave sport altogether while others may return to a lower competition level. As it has been expressed that psychological thoughts and emotions are relevant to athletes’ injury experiences, a psychological component, such as sport confidence, needs to be thoughtfully considered during the rehabilitation and return to sport process following ACL surgery.
Attention to sport confidence may assist clinicians in releasing athletes to sport, and may explain athletes’ rationale for abstaining from sport post-surgery.
Chapter 3

Objectives

The objectives of this study were two-fold; the first objective was to develop the relationship between the DVJ performance and physical attributes (anaerobic power, balance, calf girth, body fat and age) in a group of healthy participants. The second objective was to apply this model to a group of ACL reconstructed participants to determine if the strength of the relationship is the same as for the healthy group and if the relationship is improved by including confidence (determined from a survey). It was hypothesized that by including confidence the model will better predict the ACL participants’ DVJ performance.
Chapter 4

Methods

4.1 Participants

For this study the primary investigator recruited 51 participants from a university population. Participant characteristics are presented in Appendix A. All participants met the inclusion criteria of being recreationally active participating in sport and/or exercise at least 2-3 times/week for a total of 2-3 hours. The Queen’s University Research Ethics Board approved the procedures (Appendix B), and all participants gave written informed consent (Appendix C).

Sample size calculations were performed based on the results from Davis and colleagues (2003) and can be found in Appendix D. However, the calculations showed that only four participants (rounding up from 3.07) were needed for each group therefore sample size was determined by a rule of thumb, five participants per variable. As Davis and colleagues (2003) had six variables, this required a sample size of 30 and then five more were added for safety, resulting in a total of 35.

The control group consisted of 38 participants who had no current injuries or past surgeries on their lower limbs. The participants completed an exclusion questionnaire prior to participation and were included in the study if they answered no to every question (Appendix E). The participants also provided demographic information and their current activity levels to make sure they met the inclusion criteria. Due to missing data three participants were excluded from the study which resulted in a total of 35 participants in the control group. The group consisted of 18 males and 17 females. The participants had a mean age of 23 years (±1.7), a mean height of 1.74m (±0.08) and a mean body mass of 73.1kg (±13.2).

The experimental group (ACL) consisted of 13 participants who had ACL reconstructive surgery. Participants had unilateral ACL reconstructive surgery with either a patellar tendon (n=5) or
a hamstring tendon (n=8) graft within the past five years. Also, all the ACL participants successfully completed their rehabilitation programs and were released to full participation in athletics by their physician/surgeon. In addition, the participants completed the same exclusion questionnaire as the control group. The participants were included if they answered no to every question, with the exception of question 7. The participants also provided demographic information and their current activity levels to make sure they met the inclusion criteria. The ACL participants provided information regarding their surgery such as date of injury, date of surgery, graft used, leg affected, number of months of rehabilitation, cleared for sports participation and current sports status (Appendix F). The group consisted of six males and seven females. The participants had a mean age of 22 years (±2.2), a mean height of 1.72m (±0.10) and a mean body mass of 77.5kg (±16.8).

4.2 Experimental Protocol

All participants wore shorts, t-shirts and running shoes during the testing procedures. Prior to testing, participants warmed-up by walking on a treadmill for five minutes. All participants participated in four main tasks: anaerobic power test, balance test, measurements and DVJs. The measurements included calf and thigh girth, leg dominance, knee extension angle, body fat, height and weight. The order of the four main tasks was randomized and alternated the energy demanding tasks (power test and DVJs) with non-energy demanding tasks (balance and measurements) to allow for adequate rest. After the four tasks were completed the ACL participants completed the ACL-Return to Sport after Injury (ACL-RSI) scale.

4.2.1 Anaerobic Power Test

Participants completed the anaerobic power test by running up a set of stairs as fast as possible taking two steps at a time (Figure 4.1). Participants stood 1.2m in front of a staircase with 13 steps. Each step was 0.22m wide and 0.18m high. Two 131AMT ribbon switches (Tapeswitch
Corporation, London, ON, Canada), each two feet long, were mounted on the fourth and eighth step. The ribbon switches were connected to a data acquisition module, NI USB-6210 (National Instruments Corporation, Austin, TX, USA) that was connected to a laptop. A custom Labview 8.0 (National Instruments Corporation, Austin, TX, USA) computer program used the signal from the first switch to start a timer and the signal from the second switch to stop a timer, thereby measuring the time to travel from the fourth to the eighth step (Appendix G). The time was measured to the nearest millisecond. The vertical distance between the fourth and eighth steps was 0.72m.

Participants were allowed to practice the task once and then perform the test three times with a 30 second rest between trials. Participants were given the time elapsed for each trial to provide motivation for a maximal effort. The fastest time of the three trials was recorded. Power output was calculated by multiplying the participant’s weight by the participant’s velocity (vertical displacement divided by time elapsed) (Equation 1).

\[
P = w \times \frac{d}{t}
\]

Where \(P=\) power (kg m/s); \(w=\)weight of participant (kg); \(d =\)vertical displacement between the fourth and eighth step (m); and \(t=\)elapsed time between the fourth and eighth step (s). (Davis et al., 2003; Margaria, Aghemo, & Rovelli, 1966) The developers of the power test (Margaria, Aghemo, & Rovelli, 1966) used kilograms in their equation as a measure of weight but we note that Newtons should have been used. To make comparison with previous work we retained kilograms as the units for weight.
Figure 4.1: A participant performing the anaerobic power test: a) posterior view and b) sagittal view. The ribbon switches are circled and labeled.
4.2.2 Balance Test

For the balance test participants stood on a mini-trampoline and were instructed to lift one leg and close their eyes (Figure 4.2). The time that the participants were able to stand without losing their balance (defined as the other leg touching down) was recorded with a stopwatch to the nearest hundredth of a second. Participants did this twice per leg, with the starting leg being randomly selected for each participant. Participants alternated legs and had a 30 second rest between each trial. The longest trial on the dominant leg was used as the balance time. (Davis et al., 2003)

![Figure 4.2: A participant performing the balance test.](image)
4.2.3 Measurements

Calf & Thigh Girth

Participants lay on their back with their legs extended and relaxed. A flexible tape measure was used to measure both the calf girth and the thigh girth on both legs to the nearest millimeter. Calf girth was measured 102 mm below the inferior pole of the patella and thigh girth was measured 152 mm above the superior pole of the patella. Paired t-tests were performed to identify significant differences between left and right legs for the control group and the ACL group. No significant differences were found for either group, therefore the average of the left and right leg measures were used for both calf and thigh girth (Appendix H). (Davis et al., 2003)

Knee Extension Angle

Participants continued to lie on their back and rested one ankle on a small stool. A gravity reference goniometer was then used to measure the angle of the shank and the angle of the thigh with respect to the vertical to the nearest degree. The difference between these two angles was calculated and used as the maximum knee extension angle. The knee angle was measured on both legs. A paired t-test was performed to identify if there was any significant difference between the left and right knee angles for both the control group and the ACL group (Appendix H). No significant differences were found and therefore the average of the left and right knee angle was used.

Leg Dominance

The participants’ leg dominance was determined by instructing them to perform three tasks: walk up stairs, kick a ball and stand on one lower extremity. The lower extremity used for two of the three tasks was considered dominant. (Davis et al., 2003)

Height, Weight, Percent Body Fat and Skeletal Muscle Mass

While barefoot, the participants’ height was measured using a wall mounted stadiometer that measured height to the nearest centimeter. To determine body fat composition bioelectrical impedance analysis was performed using the BC-418 (Tanita Corporation, Tokyo, Japan) (Figure 4.3).
Participants were asked to remove all jewelry and other accessories and wore a standard cotton t-shirt and cotton shorts. Gender, height and age were entered into the BC-418. Participants stood on two stainless-steel foot pad electrodes mounted on the BC-418 and mass was automatically measured to the nearest milligram. Participants then held onto two metal-plated hand grips. An electric current of 50 kHz at 500µA was supplied from the anterior electrodes (tips of the toes and fingertips) and the voltage was measured at the posterior electrodes (heels and thumbs), thus the impedance is the difference between two voltage measurements (ie. left and right feet). The whole body impedance value was recorded.

![Image](image.png)

**Figure 4.3:** A participant standing on the bioelectrical impedance analyzer.

The BC-418 automatically calculated the percent body fat for each participant; however the equation used to derive percent body fat belongs to the Tanita Corporation and is confidential.
Consequently, two equations (one per gender) to calculate percent body fat were taken from the literature. Sun and colleagues (2003) developed equations to calculate fat-free mass (FFM) for both males (Equation 2) and females (Equation 3). These equations were derived using acceptable criterion measures (densitometry, isotope dilution and dual-energy X-ray absorptiometry) and were cross-validated with a population similar to ours.

\[
FFM = -9.88 + \frac{0.65hgt^2}{imp} + 0.26wgt + 0.02imp
\] (2)

\[
FFM = -11.03 + \frac{0.70hgt^2}{imp} + 0.17wgt + 0.02imp
\] (3)

Where FFM = fat free mass (kg); hgt = height (cm); imp = impedance (ohms); and wgt = weight (kg). Percent body fat (%BF) was then calculated using Equation 4. (Sun et al., 2003)

\[
%BF = \frac{wgt - FFM}{wgt} \times 100
\] (4)

Paired t-tests and correlations were performed to investigate differences between the results from Tanita versus Sun and colleagues. The percent body fats calculated by each of the equations were significantly different with a mean difference of 8.1% for the females and 10.8% for the males. However, results were strongly correlated with a correlation coefficient of 0.98 for the females and 0.99 for the males (Appendix I). Therefore, the equations from Sun and colleagues were used to calculate percent body fat as the specific equation and the factors that influence the calculation of percent body fat could be reported.
Additionally, skeletal muscle mass was calculated from the bioelectrical impedance values. Janssen and colleagues (2000) developed and cross-validated an equation with a population similar to ours and an acceptable criterion measure (magnetic resonance imaging) (Equation 5).

\[ SMM = \left( \frac{h_{\text{gt}}^2}{\text{imp}} \times 0.401 \right) + (\text{gender} \times 3.825) + (\text{age} \times -0.071) + 5.102 \]  

(5)

Where SMM = skeletal muscle mass (kg); hgt = height (cm); imp = impedance (ohms); for gender, men = 1 and women = 0; and age is in years (Janssen, Heymsfield, Baumgartner, & Ross, 2000). Percent skeletal muscle was also calculated using Equation 6.

\[ \%SM = \frac{SMM}{wgt} \times 100 \]  

(6)

Where \%SM = percent skeletal muscle and wgt = weight (kg).

4.2.4 Drop Vertical Jump (DVJ)

This task required a motion tracking system (Optotrak by Northern Digital Inc., ON, Canada) to track the motion of the DVJs (Figure 4.4). An infrared-emitting marker was placed on each of the participants’ greater trochanters to track the three-dimensional displacement of the hip during the task. A 6-channel strober was used to activate the markers. The data was collected at 100 Hz.

For the DVJs, participants stood on a 308mm high box. Many studies have used this height and higher for drop landing tasks and DVJ tasks with both ACL participants and healthy participants (Decker et al., 2002; Ortiz et al., 2008; Paterno et al., 2007; Vairo et al., 2008). Participants were instructed to drop directly down off the box by lifting one foot first, dropping off the box and, after landing, immediately jump as high as possible (Ford, Myer, & Hewett, 2003) (Figure 4.5).
Participants were allowed to practice the task until they were comfortable with it (on average 3-4 times). Before the DVJs, Optotrak data were collected for a four second standing trial to determine the participants’ reference hip height. Participants then performed five trials with one side of their body facing the camera. Due to the camera’s static position, the box was then moved and participants performed five more trials with the other side facing the camera following another standing trial. The side chosen first was randomly determined. Participants performed a total of ten trials with 30 seconds of rest between each trial. Trials were repeated if they were non-acceptable (if participants lost their balance or if technical problems arose).

Custom software developed using Matlab 6.1 (The Math Works, Natick, MA, USA) was used to process the Optotrak data to determine the DVJ outcome measures (Appendix J). The DVJ outcome measure was maximal displacement. Maximal displacement was calculated as the difference between the reference hip height and the maximum height achieved from the jump.
Figure 4.5: A drop vertical jump: a) standing on the box with the left leg lifted prior to dropping; b) landing after the drop; c) jumping as high as possible; d) landing after the jump.
4.2.5 Confidence Survey

All ACL participants completed a 12-item ACL-Return to Sport after Injury (ACL-RSI) scale (Appendix K). Participants were instructed to place a mark on the line, which they think best describes them in relation to the two descriptors (not at all or extremely). The ACL-RSI scale was scored by totaling the mark for each question and where a line was placed in between two values the mark given was the lower of the two values plus a half. The total score was then converted to a percentage where 100% indicated no negative psychological responses and a value of 0 indicated extremely negative psychological responses. (Webster et al., 2008)

4.3 Statistical Analysis

The final outcome measures were: age, weight, height, power, balance time, average calf girth, average thigh girth, average knee angle, body fat mass (relative and absolute), skeletal muscle mass (relative and absolute), maximal displacement and survey score. All variables were entered into statistical software (SPSS 17.0, Chicago, IL, USA) for analysis. Means and standard deviations were calculated for each variable. Also, correlations were performed between variables. A step-wise multiple regression analysis was performed with maximal displacement as the response variable for the control group. The developed regression model was then applied to the ACL group and the $R^2$ values were compared by inspection. The survey score was then added to the ACL group model and again the $R^2$ values were compared by inspection. The standard error of the estimate was used to determine the precision of each model. Additionally, regression analysis was performed on the separate genders.
Chapter 5

Results

A stepwise multiple regression analysis was conducted in which all variables for the control group, were entered to determine a model to predict maximum DVJ height. Multicollinearity statistics for all regression models can be found in Appendix L. The best prediction model, Model 1, had a R² value of 0.56 (Table 5.1). The model included power (p<0.05) and relative skeletal muscle mass (p<0.05). A second multiple regression analysis, using only power and relative skeletal muscle mass, was performed using the ACL data (Model 2 – Table 5.1). Model 2 had a slightly lower R² value of 0.54. However, the only significant variable was power (p<0.05). The next multiple regression analysis on the ACL group included the same variables as Model 2 and added the survey variable (Model 3 – Table 5.1). Model 3 was found to have a slightly higher R² value of 0.56 when compared to Model 2, but a similar R² value when compared to Model 1. Again, the only significant variable was power (p<0.05).

The relationship between maximum DVJ height and power, one of the two significant predictor variables from Model 1, is shown in Figure 5.1, for both the control and ACL groups. The graph depicts a positive relationship between power and height for the control group, as power increased, DVJ height also increased (r=0.64, p<0.05). In addition, the graph shows that the ACL group has the same significant positive relationship between power and DVJ height (r = 0.78, p<0.05). Division by gender also shows that females in both groups have lower power values and lower jump heights versus males in both groups. In a separate analysis of the control group by gender the relationship between power and DVJ height was insignificant (r = 0.05, p>0.05 for females and r = -0.06, p>0.05 for males). Correlations were not calculated for the ACL group as there are only seven females and six males in the group.
Table 5.1: Three regression models predicting maximum DVJ height (mm). Model 1 is the coefficients for variables selected for the control group based on stepwise selection with the model as follows: DVJ height = constant + %skeletal muscle + power; where % skeletal muscle is the relative skeletal muscle mass (%) and power is the outcome of the anaerobic power test (kg m/s) (n=35). Model 2 is the coefficients determined for the variables selected from the control group but applied to the ACL group (n=13). Model 3 is the same as Model 2 except survey, the percentage scored on the confidence survey, is added (n=13).

<table>
<thead>
<tr>
<th>Model</th>
<th>Sample size</th>
<th>Group</th>
<th>Constant</th>
<th>%Skeletal Muscle</th>
<th>Power</th>
<th>Survey</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>35</td>
<td>Control</td>
<td>-18.99</td>
<td>8.64*</td>
<td>1.23*</td>
<td>-</td>
<td>0.56</td>
<td>58.58</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>ACL</td>
<td>64.16</td>
<td>3.03</td>
<td>2.61*</td>
<td>-</td>
<td>0.54</td>
<td>87.40</td>
</tr>
<tr>
<td>3</td>
<td>13</td>
<td>ACL</td>
<td>74.75</td>
<td>0.68</td>
<td>2.32*</td>
<td>1.46</td>
<td>0.56</td>
<td>84.75</td>
</tr>
</tbody>
</table>

*p<0.05
The relationship between DVJ height and relative skeletal muscle mass, the second significant predictor variable from Model 1, is shown in Figure 5.2, for both the control and ACL groups. For the control group the graph shows a positive relationship such that as relative skeletal muscle mass increases so does DVJ height ($r = 0.69$, $p<0.01$). For the ACL group the same relationship may be seen in the graph, however it was found to be insignificant ($r = 0.44$, $p>0.05$). Similar to the power relationships, when the groups are considered by gender the graph shows a separation where females in both groups have lower relative skeletal muscle mass and lower jump heights compared to males in both groups. For the females and males in the control group the relationships were found to be insignificant ($r = 0.15$, $p>0.05$ and $r = 0.39$, $p>0.05$ respectively).

Due to these gender differences separate multiple regression analyses to predict maximum DVJ height were carried out for each gender in the control group. For the males the stepwise regression analysis found no significant predictors of DVJ height. On the contrary, for the females the stepwise regression analysis found three significant predictors of DVJ height: weight, power and knee angle ($p<0.05$ for each) (Model 4 – Table 5.2). This model was found to have a $R^2$ value of 0.59. As there were only seven females in the ACL group no further regression analyses were carried out.

In all four models previously presented power was significant and, therefore, further regression analyses were carried out to determine possible predictors for power in the control and ACL groups. As gender differences were noted in predicting DVJ height, the first regression analysis looked at predicting power for the separate genders in the control group. For the females in the control group, the stepwise regression analysis found one significant predictor of power: weight ($p<0.05$) (Model 5 – Table 5.3). Model 5 had a $R^2$ value of 0.60. For the males in the control group, the stepwise regression analysis also found weight to be the only significant predictor of power ($p<0.05$) (Model 6 – Table 5.3). This model was found to have a $R^2$ value of 0.69.
Figure 5.1: The relationship between maximum DVJ height (mm) and power (kg m/s) for both the control group and the ACL group.
Figure 5.2: The relationship between maximum DVJ height (mm) and relative skeletal muscle mass (%) for both the control group and the ACL group.
Table 5.2: The regression model for predicting the maximum height jumped during the DVJ task, DVJ height (mm) in females. Model 4 is the coefficients for variables selected from the control group’s females based on stepwise selection with the model format as follows: DVJ height = constant + weight + power + knee angle; where weight is the participants’ body mass (kg), power is the output determined by the anaerobic power test (kg m/s), and knee angle is the amount of end range knee extension (degrees) (n=17).

<table>
<thead>
<tr>
<th>Model</th>
<th>Sample Size</th>
<th>Group</th>
<th>Gender</th>
<th>Constant</th>
<th>Unstandardized Coefficients</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Weight</td>
<td>Power</td>
<td>Knee Angle</td>
</tr>
<tr>
<td>4</td>
<td>17</td>
<td>Control</td>
<td>Females</td>
<td>521.30*</td>
<td>-7.32*</td>
<td>3.29*</td>
<td>3.31*</td>
</tr>
</tbody>
</table>

*p<0.05
Since weight was found to be the only significant variable for both genders in the control group, a third regression analysis was done on the entire control group with weight as the only predictor for power (Model 7 – Table 5.4). Model 7 was found to have a $R^2$ value of 0.81, which is higher than the $R^2$ values of both Model 5 and Model 6. As the model for the entire control group had the highest $R^2$ value, the next regression analysis was done on the entire ACL group (Model 8 – Table 5.3). Model 8 was found to have a slightly lower $R^2$ value of 0.77 than that of the control group’s model. The next multiple regression analysis on the ACL group included the same variable as Model 8 with the addition of the survey variable (Model 9 – Table 5.3). Model 9 was found to have a $R^2$ value of 0.80, which is higher than the previous ACL model and yet, very similar to the $R^2$ value of the control’s model. As the $R^2$ values of Model 8 and Model 9 were quite high, the models were applied to the ACL group’s data to compare the predicted power values to the actual power values. A table which includes the actual, predicted and residual values using the two models on the ACL group’s data can be found in Appendix M.

Individual results and descriptive statistics for each variable can be found in Appendix A.

The average range of the DVJ heights for each participant in the control group and the ACL group were 70.73mm and 78.68mm respectively. The average standard deviation for each participant was 25.37mm for the control group and 34.66mm for the ACL group. All variables were checked for normality and two were found to be not normal: balance and survey. Balance was not found to be a significant predictor in any of the models and, therefore, was ignored. On the other hand, survey was used and was found to have an extreme value of 6.7% which explains the non-normality; however, this is a real value and was included in the data set. Another extreme value was found in the DVJ height of the ACL group with a value of 763mm, however, this is also a real value and was included in the analysis. It should be noted that including this case did not affect the results.

Additional relationships between variables were reviewed. Correlation tables for a subset of variables
Table 5.3: Five regression models for predicting power (kg m/s) in the females and males of the control group separately as well as in the whole control group and the whole ACL group. Model 5 is the coefficients for variables selected from the control group’s females based on stepwise selection with the model format as follows: power = weight; where weight is the participants’ body mass (kg) (n=17). Model 6 is the coefficients for variables selected for the control group’s males based on stepwise selection (n=18). Model 7 is the coefficients for the same variable from Model 5 and Model 6 but applied to the whole control group (n=35). Model 8 is the same as Model 7 but applied to the whole ACL group (n=13). Model 9 is the same as Model 8 except survey, the percentage scored on the confidence survey, was added as another variable (n=13).

<table>
<thead>
<tr>
<th>Model</th>
<th>Sample Size</th>
<th>Group</th>
<th>Gender</th>
<th>Constant</th>
<th>Unstandardized Coefficients</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>17</td>
<td>Control</td>
<td>Females</td>
<td>2.01</td>
<td>1.19*</td>
<td>0.60</td>
<td>8.14</td>
</tr>
<tr>
<td>6</td>
<td>18</td>
<td>Control</td>
<td>Males</td>
<td>15.76</td>
<td>1.35*</td>
<td>0.69</td>
<td>9.14</td>
</tr>
<tr>
<td>7</td>
<td>35</td>
<td>Control</td>
<td>Both</td>
<td>-40.56*</td>
<td>1.96*</td>
<td>0.81</td>
<td>12.35</td>
</tr>
<tr>
<td>8</td>
<td>13</td>
<td>ACL</td>
<td>Both</td>
<td>-41.07</td>
<td>1.89*</td>
<td>0.77</td>
<td>17.32</td>
</tr>
<tr>
<td>9</td>
<td>13</td>
<td>ACL</td>
<td>Both</td>
<td>-54.48*</td>
<td>1.78*</td>
<td>0.80</td>
<td>16.00</td>
</tr>
</tbody>
</table>

*p<0.05
for the control group and the ACL group as well as the females and males of the control group can be found in Appendix N.
Chapter 6

Discussion

6.1 General Discussion

How can a clinician know if an athlete is ready to return to sport? One indication is if their performance after surgery and rehabilitation has returned to its pre-injury level. While this is an excellent benchmark, it is probably not possible to determine because there is no recorded pre-injury measurement that can serve as the required benchmark. If it were possible to estimate their pre-injury performance and compare the estimated performance to their current performance, clinicians would have another indicator that the athlete is ready, or not, to return to sport. Presumably, large discrepancies between the predicted and actual performance post-injury would suggest that there are physical or perhaps psychological factors impeding performance implying that the athlete is not ready to return to sport. Because vertical jump performance has been reliably predicted from objective physical parameters and the DVJ challenges athletes who have undergone ACL reconstruction and rehabilitation, the objectives of this work were to determine if DVJ height could be predicted and if it could, would the same relationship hold for athletes who have had ACL reconstructive surgery.

Our results show that relative skeletal muscle mass and power are significant predictors of healthy participants’ DVJ performance. Similarly, Davis and colleagues (2003) examined predictors of a vertical jump and showed that percent body fat, power test time, balance test time, age and right calf girth were all significant predictors of vertical jump performance in a healthy population. We found fewer significant predictors but are in general agreement with Davis and colleagues (2003) that body composition and muscle power are related to jumping performance.

Davis and colleagues (2003) only measured percent body fat, whereas we measured body fat (relative and absolute) as well as skeletal muscle mass (relative and absolute) and there are strong correlations among these measures. Percent body fat as a significant predictor of vertical jump
performance could represent a measure of fitness level suggesting that as percent body fat increases fitness level decreases resulting in poorer jump performance. Also, percent body fat could represent a measure of dead weight that hinders jump performance so that as percent body fat increases more weight needs to be lifted during the jump and, therefore, a lower jump height is reached. For this study, skeletal muscle mass was introduced as it was thought to better reflect the muscle power required for jumping. Results of this study, showed that relative skeletal muscle mass predicted DVJ performance more precisely than relative body fat.

This study’s results also agreed with Davis and colleagues (2003) that power is a significant predictor of jumping performance, vertical and DVJ. Unfortunately, Davis and colleagues (2003) used only the time measured during the power test and not the calculated power. This is a concern as time does not necessarily represent power. Two people could run up the stairs in the same time, however, if one person weighed more than the other that person would have generated more power to move their weight up the stairs. The present study, more correctly, used the actual power calculation, determined from the equation: power = weight x distance/time, for the power outcome. Results found that power was a significant predictor of DVJ performance. A DVJ is a very short exercise of no more than 4-5 seconds duration and the power test is a measure of maximum anaerobic power output, therefore, it is reasonable that power is related to DVJ performance.

While the present study and the vertical jump (Davis et al., 2003) study have some similarities, a major difference between the two is the skill at hand; a vertical jump versus a DVJ. For many athletes, a vertical jump is a simple skill that can be easily performed, but a DVJ involving plyometrics may be more difficult. This could be because of unfamiliarity with the task as well as the addition of more factors that influence DVJ performance, such as the magnitude of the countermovement and ground contact time. Davis and colleagues (2003) found that the mean vertical jump height was 598mm with a standard deviation of 97mm. The mean DVJ height in our healthy population was 416mm with a standard deviation of 88mm, which is quite similar to Davis
and colleagues (2003). However, the average range of heights for the ten DVJ trials per participant was 70.73mm, indicating little consistency in participants reaching similar heights during the ten trials. It appears that the more complex DVJ is more variable than the simple vertical jump and it may be harder to predict DVJ performance with a simple model. This may explain why the regression outcomes were poorer for the DVJ ($R^2=0.56$) than for the vertical jump ($R^2=0.87$).

The second objective of this study applied the healthy participants’ model to the ACL participants. This allowed us to compare the relationship between physical characteristics and DVJ performance between the two groups. For the ACL group, the strength of the relationship between the predictors and DVJ performance changed a small amount when compared to the healthy group. However, there was a difference in the two models. The healthy model had both relative skeletal muscle mass and power as significant predictors while the ACL model had only one significant predictor, power.

The next part of the second objective was to use the ACL model again, but to include the survey scores as an additional predictor of DVJ performance. If including the survey scores improves the precision of the prediction of DVJ performance then sport confidence has an association with performance. The survey used in this study was developed as a measure of psychological impact of returning to sport following ACL surgery and encompassed related emotions, confidence in performance and risk appraisal (Webster et al., 2008). The model of response to sport injury developed by Wiese-Bjornstal and colleagues (1998) exhibits three areas of response to injury: behavioural, cognitive and emotional. The survey used here includes both cognitive responses, such as self-perceptions and beliefs, and emotional responses, such as fear and attitude but did not include behaviours. Additionally, Tripp and colleagues (2007) found that fear of re-injury, negative affect and pain catastrophizing were all significantly correlated with athlete’s confidence. Therefore, the survey scores can be seen as a measurement of one’s sport confidence. When the survey scores were added into the analysis the strength of the relationship between the
predictors and DVJ performance did not change drastically and power remained the only significant predictor. This finding does not support the hypothesis that including confidence will predict the ACL participants’ DVJ performance more precisely. As a result, it can be concluded that confidence does not have an association with DVJ performance for athletes who after ACL surgery have been cleared to return to sport.

ACL injuries affect both male and female athletes and both genders were included in the present study, unlike Davis and colleagues’ study (2003) which had only male participants. Graphic presentation of the results showed a clear difference in the DVJ performance of the two genders. This warranted further analyses to examine DVJ performance for each gender in the control group.

While Davis and colleagues (2003) found five significant predictors of vertical jump performance in males our results showed no significant predictors of DVJ performance. Therefore, there is no relationship between any of the variables measured in this study and the DVJ performance for the males. Perhaps other physical characteristics that were not measured in this study, such as muscular strength or lower limb flexibility, are related to DVJ performance, a question that requires further investigation. Another explanation for these findings may be the highly variable outcome of the DVJ task.

On the other hand, there were three significant predictors of female DVJ performance: weight, power and knee angle. The relationship between weight and DVJ performance for females was found to be negative indicating that as weight increases DVJ height decreases. Weight was also found to be negatively correlated with relative skeletal muscle mass. So as weight increases relative skeletal muscle mass decreases. For the entire control group weight is positively correlated with DVJ height. Likely, this is driven by the relationship between weight and height across both genders where the men are heavier and jump higher than the women. However, within both groups an increase in weight increases both the absolute amount of body fat and the skeletal muscle mass, but the proportion of skeletal muscle mass goes down as weight increases. In the female control group
increased weight reduces DVJ performance as body fat is added with increasing weight. There is likely an optimal body composition model that has the weight needed to maintain the required skeletal muscle mass that is also within an acceptable range of body fat.

The second significant predictor of DVJ height for the control group’s females was power. This is in agreement with the model for the entire control group as power was also a significant predictor for DVJ height. The relationship between power and DVJ height was also found to be positive, suggesting that as power increases so does DVJ height.

The last significant predictor for the females in the control group was knee angle. The relationship between knee angle and DVJ height is positive, signifying that as knee angle increases DVJ height also increases. Knee angle refers to the amount of end-range extension and as extension is positive, a positive knee angle indicates some degree of hyperextension. Knee angle may be related to DVJ height as a measure of knee joint range of motion or lower limb flexibility. This suggests that the more range of motion present in the knee or the more flexible the lower limbs are the higher the DVJ will be. Further research regarding knee angle and its relation to DVJ performance is required.

Analysis of the control group by gender found only a model for the females; the next step would have been to apply this model to the females of the ACL group. Unfortunately, when the ACL group is separated by gender the total number of females in the ACL group is seven and, as a result, further regression analyses could not be carried out. If future studies recruit more females in the ACL group, the three predictors: weight, power and knee angle, could be thoroughly evaluated to determine if they are significant predictors of DVJ performance for females who have had ACL surgery.

As the results showed that DVJ performance could not be predicted precisely, evaluation of the other performance measures was performed to determine if a different measure of performance could be predicted from the physical characteristics. Power was a significant variable in all models that predicted DVJ height, thus further analyses attempting to predict power were carried out.
Similar methods used in trying to predict DVJ height were used to predict power, but since a distinction between genders was noted in the DVJ analyses, the models to predict power were determined for the separate genders first. Results showed that power could be precisely predicted using weight as the only significant predictor for both males and females of the control group. For the entire control group power could be predicted more precisely than the DVJ performance. Results for the ACL group showed a similar finding that weight could also predict power performance better than the DVJ performance. The reason that power is more precisely predicted than DVJ height may lie in the simplicity of the power test. Like a simple vertical jump, it is less technical than a DVJ and most people have experience using stairs.

Further analysis found that by adding the survey score, a measure of confidence, into the model to predict power for the ACL group, power could not be more precisely predicted. However, if confidence played a role in performance of the power test for the ACL participants and it may explain why the survey score was not a factor in predicting DVJ performance. If power predicts DVJ height and both the power test and the DVJ are affected by confidence then the variation due to confidence is already accounted for in the measure of power and we would never see the association of confidence and DVJ performance when power is included as a predictor.

It may be that both DVJ height and power have physical and psychological components suggesting that neither measure is purely objective. In fact, the relationship between confidence and DVJ height could be mediated by power. Maximal tests such as maximal voluntary contractions or the DVJ used here require motivation to achieve maximal performance. We proposed to predict this maximal performance with a series of objective measures. However, the power test is itself a maximal test and requires motivation as well. Therefore, with power as a mediator this does not allow us to distinguish between the performer’s physical characteristics and the motivational state, which is important when we are trying to examine the association of sport confidence. Simply, a poor
power performance quite nicely predicts a poor DVJ performance with both being affected by some psychological factor to a similar extent.

Contrary to this, weight is the sole predictor of power and is definitely an objective measure. Therefore, using the power prediction models to compare the predicted and actual power performance may help clinicians evaluate athletes after ACL surgery. The use of the power test has many advantages: simple set-up, the skill does not require training, it does not lead to exhaustion, the operator does not need any specific knowledge, and the exercise involves a large fraction of muscles in the body (Margaria et al., 1966). Future research regarding predicting power performance is warranted as it may be a simple yet beneficial tool for clinicians.

As mentioned in the results, there was an extreme value within the survey scores; a value of 6.7% was recorded. This extreme value required further examination. Since power was predicted more precisely than DVJ performance, the power models were applied to this specific participant. First Model 8, where weight was the only predictor for power, was applied to the participant and the predicted power was 102.95kg m/s, which was higher than the participant’s actual power value of 76.2kg m/s. Next, Model 9, where weight and survey were the predictors for power, was applied to the participant and the predicted value was 83.38kg m/s, which was much closer to the participant’s actual value. This particular case demonstrates that by including the extremely low survey score, the participant’s predicted power was much closer to the actual power than the prediction with weight alone. Consequently, for this participant, confidence played a considerable role in their performance on the power test. This suggests that confidence may only be associated with a participants’ performance when it is extremely low. The next lowest survey score was 40.4% and the same models were applied to this different participant, however, the difference between the two predicted values was small with the actual power value falling in between the two predicted values. This introduces the idea that a threshold may exist, where if the survey score is below this threshold, performance may be significantly associated with one’s confidence, but if the survey score is above
this threshold then performance is not associated. Further research is required to test this theory and to determine the value of this threshold.

6.2 Clinical Relevance

The findings of the present study may be very useful for clinicians who deal with athletes after ACL reconstructive surgery. The initial purpose of this study was to develop a tool that involved clinicians measuring an athlete’s physical attributes, entering these measures into a model to predict DVJ performance and then comparing this prediction to their actual DVJ performance. The results could then be used as a means of determining if an athlete is ready to return to sport following their surgery and rehabilitation. However, initial findings showed that DVJ performance was quite difficult to predict. Also, the same prediction model could not be used for both genders. The male model was nonexistent and the female model had a large standard error of the estimate. Consequently, we feel that none of the DVJ prediction models can be used in a clinical setting.

Although the DVJ findings were disappointing, it was still worthwhile to investigate if confidence should be considered when clinicians evaluate ACL athletes’ performance. While confidence was not a predictor of DVJ performance or power performance it was a predictor of power for the particular case study. The case study of the participant who had an extremely low survey score showed that confidence was associated with their performance on the power test. Therefore, whether or not confidence is associated with performance is inconclusive and requires further study.

An important finding from this study was that power could be more precisely predicted than DVJ performance. This may be quite useful for clinicians as the sole predictor of power was body weight. Clinicians could measure an athlete’s weight, enter it into the power model and then compare the predicted value with the actual value from the power test for an evaluation of performance. This test is very simple and weight is a definite objective measure, which confidence
cannot affect. And if future studies conclude that confidence should be considered when evaluating performance, the implementation of a confidence survey and a model to predict performance could be easily developed. To our knowledge, this is the first study to find a satisfactory test that can be used to evaluate performance by comparing predicted values to actual values.

6.3 Limitations

The current study’s limitations should be acknowledged. The first limitation concerns the participants. As the participants in both groups were recreationally active and between the ages of 20-28 years old the results can only be generalized to this specific population. Also, the participants in the ACL group had only one ACL reconstruction, meaning the results cannot be applied to more complex cases where both legs were affected or a previously reconstructed ACL was re-injured. During recruiting there was a prevalence of more complex cases and, consequently, fewer ACL participants were recruited than were expected. This lower number of ACL participants limited the findings when gender differences were acknowledged.

A second limitation is related to the DVJ task. As not all athletes are familiar with plyometrics, depending on their sport, the DVJ may be a new skill for the participants. Also, the DVJ is more complex than a simple vertical jump and there are additional factors that may influence the performance, such as the magnitude of the countermovement and ground contact time. Because some participants may have found this a novel task and the DVJ requires more technique, the participants may have required more practice and instructions in order to perform the task to the best of their capabilities. Furthermore, the complexity of the task may have affected participants’ confidence as confidence is related to task mastery, meaning the more one masters a task the more confident they are with that task.

Since the second objective was to examine the association of confidence and performance for the ACL group, the control group did not complete any surveys to measure their psychological
thoughts and emotions. Since the DVJ task requires maximal effort, there may be psychological influences such as motivation and arousal that affect DVJ performance. As these psychological factors were not measured, it cannot be concluded as to whether or not psychological influences exist and if they affected the control group’s performance.

The final limitation is specific to the confidence survey. The questions on the survey are related to the participant’s current sport. However, if the sport is swimming or rowing, an athlete’s confidence may be artificially high as there is not much risk of injuring their knee in those sports compared to sports like rugby or basketball. For example, one ACL participant mentioned that she used to play volleyball and it was in that sport that she tore her ACL. Following her surgery and rehabilitation, when she was ready to return to sport, she decided not to return to volleyball, but instead to devote more attention to swimming. Having this participant fill out the survey considering volleyball might lead to quite a different score than having her fill it out while considering swimming. The survey is not a good measure of confidence in general athletic activities because it is specific to one’s current athletic involvement. Additionally, the survey is not specific to the task at hand, the DVJ and confidence is specific to the task. Therefore asking about how confident one is in their current sport may not show how confident they are at performing a DVJ. Ideally, a survey specific to the DVJ is required to test the association of confidence and performance. However, the survey used in this study was the most relevant available in the literature.

6.4 Conclusions

This study showed that DVJ performance cannot be predicted precisely by physical characteristics such as height, weight, calf girth, thigh girth, knee angle, power, balance, body fat and skeletal muscle. This study also showed that DVJ performance differs between males and females, and that separate prediction models for DVJ performance are needed. Additionally, this study showed that one’s sport confidence, after ACL surgery, is not directly associated with DVJ
performance. On the other hand, this study did show that power performance can be predicted from the true objective measure of weight. More research regarding predicting power and using it as a tool to measure performance following surgery and rehabilitation is required. Furthermore, this study showed that for ACL participants, confidence may be associated with one’s performance of the power test, and this association may be present when one’s confidence is extremely low, suggesting a threshold above which confidence is not associated with performance. Future research is needed to test this theory and determine the value of this possible threshold. It remains inconclusive as to whether or not confidence may play a role in jumping performance after ACL surgery.
References


Appendices
APPENDIX A

Control Group and ACL Group Data
Table A1: Control participants’ results for gender, age (years), height (m), mass (kg), leg dominancy, average calf girth (mm), average thigh girth (mm), average knee angle (°), power (kg m/s), balance (s), relative body fat (%), body fat mass (kg), relative skeletal muscle (%), skeletal muscle mass (kg), and DVJ height displacement (mm).

<table>
<thead>
<tr>
<th>Subject Number</th>
<th>Gender</th>
<th>Age (years)</th>
<th>Height (m)</th>
<th>Mass (kg)</th>
<th>Leg</th>
<th>Dominant</th>
<th>Avg Calf Girth (mm)</th>
<th>Avg Thigh Girth (mm)</th>
<th>Avg Knee Angle (°)</th>
<th>Power (kg m/s)</th>
<th>Balance (s)</th>
<th>% Body Fat</th>
<th>Body Fat Mass (kg)</th>
<th>% Skeletal Muscle</th>
<th>Skeletal Muscle Mass (kg)</th>
<th>DVJ Hgt Displacement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>22</td>
<td>1.63</td>
<td>61.1</td>
<td>Right</td>
<td>357.5</td>
<td>500.0</td>
<td>11.5</td>
<td>69.07</td>
<td>7.12</td>
<td>24.1</td>
<td>14.7</td>
<td>31.5</td>
<td>19.2</td>
<td>394.0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>23</td>
<td>1.78</td>
<td>86.4</td>
<td>Right</td>
<td>400.0</td>
<td>555.0</td>
<td>23.0</td>
<td>104.94</td>
<td>2.94</td>
<td>30.7</td>
<td>26.5</td>
<td>27.1</td>
<td>23.4</td>
<td>336.2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>25</td>
<td>1.60</td>
<td>59.0</td>
<td>Right</td>
<td>359.5</td>
<td>499.0</td>
<td>7.5</td>
<td>60.86</td>
<td>23.30</td>
<td>23.9</td>
<td>14.1</td>
<td>31.8</td>
<td>18.8</td>
<td>279.6</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>25</td>
<td>1.70</td>
<td>63.4</td>
<td>Right</td>
<td>375.0</td>
<td>507.5</td>
<td>16.5</td>
<td>77.13</td>
<td>24.07</td>
<td>19</td>
<td>12.0</td>
<td>34.4</td>
<td>21.8</td>
<td>337.9</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>21</td>
<td>1.80</td>
<td>78.1</td>
<td>Right</td>
<td>375.0</td>
<td>542.5</td>
<td>2.0</td>
<td>120.76</td>
<td>14.97</td>
<td>14.2</td>
<td>11.1</td>
<td>39.2</td>
<td>30.6</td>
<td>539.5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>21</td>
<td>1.68</td>
<td>59.3</td>
<td>Right</td>
<td>362.5</td>
<td>472.5</td>
<td>8.5</td>
<td>74.67</td>
<td>75.44</td>
<td>24.6</td>
<td>14.6</td>
<td>30.2</td>
<td>17.9</td>
<td>366.3</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>22</td>
<td>1.76</td>
<td>61.5</td>
<td>Right</td>
<td>370.0</td>
<td>467.5</td>
<td>6.0</td>
<td>77.44</td>
<td>7.40</td>
<td>19</td>
<td>11.7</td>
<td>33.3</td>
<td>20.5</td>
<td>375.2</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>F</td>
<td>22</td>
<td>1.80</td>
<td>88.5</td>
<td>Right</td>
<td>402.5</td>
<td>560.0</td>
<td>7.0</td>
<td>120.74</td>
<td>56.84</td>
<td>15.8</td>
<td>14.0</td>
<td>38.5</td>
<td>34.0</td>
<td>428.2</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>22</td>
<td>1.75</td>
<td>81.1</td>
<td>Right</td>
<td>380.0</td>
<td>572.5</td>
<td>20.5</td>
<td>111.92</td>
<td>6.81</td>
<td>14.5</td>
<td>11.8</td>
<td>39.8</td>
<td>32.3</td>
<td>475.2</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>24</td>
<td>1.56</td>
<td>54.8</td>
<td>Right</td>
<td>350.0</td>
<td>472.5</td>
<td>12.5</td>
<td>62.34</td>
<td>89.28</td>
<td>25.1</td>
<td>13.8</td>
<td>31.1</td>
<td>17.0</td>
<td>407.4</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>F</td>
<td>25</td>
<td>1.65</td>
<td>58.7</td>
<td>Right</td>
<td>356.5</td>
<td>505.0</td>
<td>16.0</td>
<td>82.27</td>
<td>13.97</td>
<td>19.7</td>
<td>11.6</td>
<td>34.0</td>
<td>20.0</td>
<td>428.9</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>F</td>
<td>25</td>
<td>1.82</td>
<td>86.6</td>
<td>Right</td>
<td>374.0</td>
<td>537.5</td>
<td>6.5</td>
<td>132.20</td>
<td>34.88</td>
<td>16.7</td>
<td>14.5</td>
<td>37.2</td>
<td>32.2</td>
<td>380.5</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>M</td>
<td>21</td>
<td>1.82</td>
<td>79.3</td>
<td>Right</td>
<td>372.5</td>
<td>527.5</td>
<td>9.0</td>
<td>125.59</td>
<td>20.38</td>
<td>14.9</td>
<td>11.8</td>
<td>38.7</td>
<td>30.7</td>
<td>382.5</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>F</td>
<td>22</td>
<td>1.71</td>
<td>56.1</td>
<td>Right</td>
<td>322.5</td>
<td>450.0</td>
<td>5.0</td>
<td>67.00</td>
<td>34.62</td>
<td>15.9</td>
<td>8.9</td>
<td>35.6</td>
<td>20.0</td>
<td>325.5</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>M</td>
<td>22</td>
<td>1.79</td>
<td>79.3</td>
<td>Right</td>
<td>379.0</td>
<td>547.5</td>
<td>6.5</td>
<td>80.51</td>
<td>19.38</td>
<td>25.8</td>
<td>18.1</td>
<td>30.4</td>
<td>21.3</td>
<td>333.7</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>F</td>
<td>20</td>
<td>1.69</td>
<td>70.1</td>
<td>Right</td>
<td>379.0</td>
<td>547.5</td>
<td>6.5</td>
<td>80.51</td>
<td>19.38</td>
<td>25.8</td>
<td>18.1</td>
<td>30.4</td>
<td>21.3</td>
<td>333.7</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>M</td>
<td>26</td>
<td>1.84</td>
<td>87.0</td>
<td>Right</td>
<td>381.0</td>
<td>539.0</td>
<td>12.0</td>
<td>137.78</td>
<td>5.15</td>
<td>18.6</td>
<td>16.2</td>
<td>35.0</td>
<td>30.5</td>
<td>482.5</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>F</td>
<td>20</td>
<td>1.65</td>
<td>73.7</td>
<td>Right</td>
<td>367.5</td>
<td>535.0</td>
<td>14.5</td>
<td>87.88</td>
<td>4.47</td>
<td>30.5</td>
<td>22.5</td>
<td>27.9</td>
<td>20.5</td>
<td>277.3</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>M</td>
<td>22</td>
<td>1.78</td>
<td>84.6</td>
<td>Right</td>
<td>412.5</td>
<td>527.5</td>
<td>7.5</td>
<td>139.19</td>
<td>60.65</td>
<td>9.5</td>
<td>8.0</td>
<td>43.1</td>
<td>36.4</td>
<td>438.9</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>F</td>
<td>21</td>
<td>1.69</td>
<td>55.6</td>
<td>Left</td>
<td>340.0</td>
<td>455.0</td>
<td>13.0</td>
<td>61.98</td>
<td>2.37</td>
<td>16</td>
<td>8.9</td>
<td>35.8</td>
<td>19.9</td>
<td>367.5</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>M</td>
<td>24</td>
<td>1.78</td>
<td>107.0</td>
<td>Right</td>
<td>420.0</td>
<td>605.0</td>
<td>8.0</td>
<td>167.25</td>
<td>24.63</td>
<td>24.5</td>
<td>26.2</td>
<td>32.5</td>
<td>34.8</td>
<td>516.7</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>M</td>
<td>22</td>
<td>1.69</td>
<td>74.0</td>
<td>Left</td>
<td>357.5</td>
<td>502.5</td>
<td>0.5</td>
<td>125.49</td>
<td>5.00</td>
<td>17.1</td>
<td>12.7</td>
<td>38.1</td>
<td>28.2</td>
<td>393.1</td>
<td></td>
</tr>
</tbody>
</table>
Table A1 continued

<table>
<thead>
<tr>
<th>Subject Number</th>
<th>Gender</th>
<th>Age (years)</th>
<th>Height (m)</th>
<th>Mass (kg)</th>
<th>Dominant Leg</th>
<th>Avg Calf Girth (mm)</th>
<th>Avg Thigh Girth (mm)</th>
<th>Avg Knee Angle (°)</th>
<th>Power (kg m/s)</th>
<th>Balance (s)</th>
<th>% Body Fat</th>
<th>Body Fat Mass (kg)</th>
<th>% Skeletal Muscle</th>
<th>Skeletal Muscle Mass (kg)</th>
<th>DVJ Hgt Displacement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>M</td>
<td>21</td>
<td>1.90</td>
<td>92.4</td>
<td>Right</td>
<td>387.5</td>
<td>540.0</td>
<td>17.5</td>
<td>125.83</td>
<td>8.91</td>
<td>18.9</td>
<td>17.5</td>
<td>34.5</td>
<td>31.9</td>
<td>465.2</td>
</tr>
<tr>
<td>25</td>
<td>M</td>
<td>25</td>
<td>1.78</td>
<td>66.4</td>
<td>Right</td>
<td>337.5</td>
<td>465.0</td>
<td>1.0</td>
<td>100.72</td>
<td>3.22</td>
<td>7.2</td>
<td>4.8</td>
<td>44.5</td>
<td>29.6</td>
<td>401.7</td>
</tr>
<tr>
<td>26</td>
<td>F</td>
<td>24</td>
<td>1.61</td>
<td>54.3</td>
<td>Right</td>
<td>365.0</td>
<td>477.5</td>
<td>24.0</td>
<td>72.03</td>
<td>24.46</td>
<td>18.2</td>
<td>9.9</td>
<td>35.2</td>
<td>19.1</td>
<td>419.5</td>
</tr>
<tr>
<td>27</td>
<td>F</td>
<td>21</td>
<td>1.77</td>
<td>74.2</td>
<td>Right</td>
<td>370.0</td>
<td>535.0</td>
<td>5.0</td>
<td>91.98</td>
<td>3.13</td>
<td>25.2</td>
<td>18.7</td>
<td>30.1</td>
<td>22.3</td>
<td>281.2</td>
</tr>
<tr>
<td>29</td>
<td>F</td>
<td>25</td>
<td>1.62</td>
<td>65.3</td>
<td>Right</td>
<td>370.0</td>
<td>522.5</td>
<td>9.5</td>
<td>101.62</td>
<td>62.84</td>
<td>28.3</td>
<td>18.5</td>
<td>28.9</td>
<td>18.9</td>
<td>406</td>
</tr>
<tr>
<td>30</td>
<td>F</td>
<td>24</td>
<td>1.73</td>
<td>60.3</td>
<td>Right</td>
<td>335.0</td>
<td>465.0</td>
<td>8.0</td>
<td>78.40</td>
<td>1.85</td>
<td>21.9</td>
<td>13.2</td>
<td>31.4</td>
<td>19.0</td>
<td>342.7</td>
</tr>
<tr>
<td>31</td>
<td>M</td>
<td>23</td>
<td>1.77</td>
<td>67.7</td>
<td>Right</td>
<td>345.0</td>
<td>457.5</td>
<td>8.0</td>
<td>111.90</td>
<td>7.78</td>
<td>8.5</td>
<td>5.8</td>
<td>43.7</td>
<td>29.6</td>
<td>568.1</td>
</tr>
<tr>
<td>32</td>
<td>M</td>
<td>23</td>
<td>1.94</td>
<td>92.7</td>
<td>Right</td>
<td>377.5</td>
<td>547.5</td>
<td>6.5</td>
<td>140.02</td>
<td>7.72</td>
<td>14.2</td>
<td>13.2</td>
<td>37.9</td>
<td>35.1</td>
<td>534.4</td>
</tr>
<tr>
<td>33</td>
<td>M</td>
<td>22</td>
<td>1.81</td>
<td>88.2</td>
<td>Left</td>
<td>412.5</td>
<td>550.0</td>
<td>16.5</td>
<td>145.45</td>
<td>7.09</td>
<td>13.8</td>
<td>12.2</td>
<td>39.9</td>
<td>35.2</td>
<td>446.3</td>
</tr>
<tr>
<td>34</td>
<td>M</td>
<td>22</td>
<td>1.77</td>
<td>71.4</td>
<td>Right</td>
<td>365.0</td>
<td>497.5</td>
<td>19.0</td>
<td>114.34</td>
<td>5.03</td>
<td>10</td>
<td>7.1</td>
<td>42.7</td>
<td>30.5</td>
<td>554.4</td>
</tr>
<tr>
<td>35</td>
<td>M</td>
<td>21</td>
<td>1.75</td>
<td>70.5</td>
<td>Right</td>
<td>347.5</td>
<td>515.0</td>
<td>9.5</td>
<td>101.99</td>
<td>43.25</td>
<td>11.8</td>
<td>8.3</td>
<td>41.6</td>
<td>29.3</td>
<td>499.6</td>
</tr>
<tr>
<td>36</td>
<td>M</td>
<td>25</td>
<td>1.79</td>
<td>78.4</td>
<td>Left</td>
<td>377.5</td>
<td>540.0</td>
<td>15.0</td>
<td>133.89</td>
<td>16.69</td>
<td>11.5</td>
<td>9.0</td>
<td>41.4</td>
<td>32.4</td>
<td>612.3</td>
</tr>
<tr>
<td>37</td>
<td>M</td>
<td>25</td>
<td>1.76</td>
<td>82.3</td>
<td>Left</td>
<td>405.0</td>
<td>535.0</td>
<td>8.5</td>
<td>117.88</td>
<td>4.00</td>
<td>9.7</td>
<td>8.0</td>
<td>43.1</td>
<td>35.5</td>
<td>493.4</td>
</tr>
<tr>
<td>38</td>
<td>F</td>
<td>23</td>
<td>1.66</td>
<td>68.5</td>
<td>Left</td>
<td>360.0</td>
<td>517.5</td>
<td>11.0</td>
<td>74.06</td>
<td>40.13</td>
<td>27.7</td>
<td>19.0</td>
<td>29.1</td>
<td>20.0</td>
<td>268.3</td>
</tr>
<tr>
<td>Average</td>
<td>23</td>
<td>1.73</td>
<td>73.1</td>
<td></td>
<td></td>
<td>370.6</td>
<td>515.6</td>
<td>10.7</td>
<td>102.78</td>
<td>21.99</td>
<td>18.5</td>
<td>13.4</td>
<td>35.7</td>
<td>26.2</td>
<td>416.0</td>
</tr>
<tr>
<td>±stdev</td>
<td>1.7</td>
<td>±0.08</td>
<td>±13.16</td>
<td></td>
<td></td>
<td>±22.9</td>
<td>±37.4</td>
<td>±5.80</td>
<td>±28.53</td>
<td>±22.92</td>
<td>±6.48</td>
<td>±5.16</td>
<td>±6.52</td>
<td>±88.49</td>
<td></td>
</tr>
</tbody>
</table>
Table A2: ACL participants’ results for gender, age (years), height (m), mass (kg), leg dominancy, average calf girth (mm), average thigh girth (mm), average knee angle (°), power (kg m/s), balance (s), relative body fat (%), body fat mass (kg), relative skeletal muscle (%), skeletal muscle mass (kg), DVJ height displacement (mm) and survey score (%).

<table>
<thead>
<tr>
<th>Subject Number</th>
<th>Gender</th>
<th>Age (years)</th>
<th>Height (m)</th>
<th>Mass (kg)</th>
<th>Leg</th>
<th>Avg Calf Girth (mm)</th>
<th>Avg Thigh Girth (mm)</th>
<th>Avg Knee Angle (°)</th>
<th>Power (kg m/s)</th>
<th>Balance (s)</th>
<th>% Body Fat</th>
<th>Body Fat Mass (kg)</th>
<th>% Skeletal Muscle</th>
<th>Skeletal Muscle Mass (kg)</th>
<th>DVJ Hgt Displacement (mm)</th>
<th>Survey Score (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>22</td>
<td>1.63</td>
<td>71.5</td>
<td>Right</td>
<td>392.5</td>
<td>565.0</td>
<td>16.0</td>
<td>87.73</td>
<td>10.50</td>
<td>31.3</td>
<td>22.4</td>
<td>19.5</td>
<td>27.3</td>
<td>367.4</td>
<td>67.5</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>22</td>
<td>1.75</td>
<td>84.7</td>
<td>Right</td>
<td>388.5</td>
<td>550.0</td>
<td>3.0</td>
<td>130.97</td>
<td>12.28</td>
<td>19.3</td>
<td>16.3</td>
<td>30.4</td>
<td>35.9</td>
<td>562.2</td>
<td>75.8</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>20</td>
<td>1.70</td>
<td>77</td>
<td>Right</td>
<td>402.5</td>
<td>555.0</td>
<td>9.5</td>
<td>99.39</td>
<td>46.00</td>
<td>28.4</td>
<td>21.9</td>
<td>22.5</td>
<td>29.2</td>
<td>499.5</td>
<td>79.2</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>21</td>
<td>1.68</td>
<td>60.3</td>
<td>Right</td>
<td>367.5</td>
<td>460.0</td>
<td>11.5</td>
<td>70.84</td>
<td>18.53</td>
<td>22</td>
<td>13.3</td>
<td>19.4</td>
<td>32.2</td>
<td>339.0</td>
<td>59.2</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>25</td>
<td>1.74</td>
<td>70.2</td>
<td>Right</td>
<td>367.5</td>
<td>480.0</td>
<td>10.5</td>
<td>102.80</td>
<td>14.81</td>
<td>10.3</td>
<td>7.2</td>
<td>30.0</td>
<td>42.7</td>
<td>427.3</td>
<td>60.8</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>22</td>
<td>1.90</td>
<td>100.9</td>
<td>Right</td>
<td>380.0</td>
<td>530.0</td>
<td>4.0</td>
<td>141.69</td>
<td>5.18</td>
<td>19.5</td>
<td>19.7</td>
<td>34.8</td>
<td>34.5</td>
<td>391.2</td>
<td>51.7</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>21</td>
<td>1.62</td>
<td>61.7</td>
<td>Right</td>
<td>382.5</td>
<td>530.0</td>
<td>9.0</td>
<td>71.90</td>
<td>54.72</td>
<td>21.5</td>
<td>13.3</td>
<td>20.8</td>
<td>33.8</td>
<td>350.8</td>
<td>95.8</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>22</td>
<td>1.56</td>
<td>51.1</td>
<td>Right</td>
<td>355.0</td>
<td>502.5</td>
<td>8.5</td>
<td>65.96</td>
<td>228.62</td>
<td>21</td>
<td>10.7</td>
<td>17.2</td>
<td>33.7</td>
<td>323.9</td>
<td>70.0</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>24</td>
<td>1.83</td>
<td>99.9</td>
<td>Left</td>
<td>412.5</td>
<td>580.0</td>
<td>1.5</td>
<td>120.11</td>
<td>4.63</td>
<td>22.6</td>
<td>22.6</td>
<td>32.6</td>
<td>32.6</td>
<td>494.6</td>
<td>87.1</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>28</td>
<td>1.65</td>
<td>76.2</td>
<td>Right</td>
<td>395.0</td>
<td>560.0</td>
<td>23.0</td>
<td>78.61</td>
<td>2.89</td>
<td>32.8</td>
<td>25.0</td>
<td>20.1</td>
<td>26.4</td>
<td>282.0</td>
<td>6.7</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>22</td>
<td>1.78</td>
<td>90.7</td>
<td>Left</td>
<td>395.0</td>
<td>565.0</td>
<td>12.5</td>
<td>163.03</td>
<td>12.75</td>
<td>17.9</td>
<td>16.2</td>
<td>33.7</td>
<td>37.1</td>
<td>763.0</td>
<td>90.0</td>
</tr>
<tr>
<td>12</td>
<td>0</td>
<td>20</td>
<td>1.64</td>
<td>62.2</td>
<td>Right</td>
<td>385.0</td>
<td>535.0</td>
<td>8.5</td>
<td>72.37</td>
<td>29.25</td>
<td>24.9</td>
<td>15.5</td>
<td>19.2</td>
<td>30.9</td>
<td>407.2</td>
<td>40.4</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>23</td>
<td>1.88</td>
<td>100.9</td>
<td>Right</td>
<td>400.0</td>
<td>575.0</td>
<td>3.0</td>
<td>167.93</td>
<td>24.34</td>
<td>18.3</td>
<td>18.5</td>
<td>36.2</td>
<td>35.9</td>
<td>516.9</td>
<td>91.7</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>22</td>
<td>1.72</td>
<td>77.5</td>
<td></td>
<td>386.4</td>
<td>537.5</td>
<td>9.3</td>
<td>105.64</td>
<td>35.73</td>
<td>22.3</td>
<td>17.2</td>
<td>33.2</td>
<td>25.9</td>
<td>440.4</td>
<td>67.4</td>
</tr>
<tr>
<td>±stdev</td>
<td></td>
<td>±2.2</td>
<td>±0.11</td>
<td>±16.81</td>
<td></td>
<td>±16.0</td>
<td>±36.9</td>
<td>±5.91</td>
<td>±35.89</td>
<td>±60.05</td>
<td>±6.01</td>
<td>±5.19</td>
<td>±4.35</td>
<td>±7.08</td>
<td>±128.2</td>
<td>±24.7</td>
</tr>
</tbody>
</table>
APPENDIX B

Ethics Approval Sheet
QUEEN'S UNIVERSITY HEALTH SCIENCES & AFFILIATED TEACHING HOSPITALS RESEARCH ETHICS BOARD

January 8, 2009

Ms. Robin Goody
School of Kinesiology and Health Studies
Physical Education Centre
Queen’s University

Dear Ms. Goody,

Study Title: The Effect of Sport Confidence on Drop Vertical Jump Performance After Anterior Cruciate Ligament Reconstruction
Co-Investigators: Dr. Patrick Costigan

I am writing to acknowledge receipt of your recent ethics submission. We have examined the protocol and consent form for your project (as stated above) and consider it to be ethically acceptable. This approval is valid for one year from the date of the Chair's signature below. This approval will be reported to the Research Ethics Board. Please attend carefully to the following list of ethics requirements you must fulfill over the course of your study:

➢ Reporting of Amendments: If there are any changes to your study (e.g. consent, protocol, study procedures, etc.), you must submit an amendment to the Research Ethics Board for approval. (see http://www.queensu.ca/vpr/reb.html).

➢ Reporting of Serious Adverse Events: Any unexpected serious adverse event occurring locally must be reported within 2 working days or earlier if required by the study sponsor. All other serious adverse events must be reported within 15 days after becoming aware of the information.

➢ Reporting of Complaints: Any complaints made by participants or persons acting on behalf of participants must be reported to the Research Ethics Board within 7 days of becoming aware of the complaint. Note: All documents supplied to participants must have the contact information for the Research Ethics Board.

➢ Annual Renewal: Prior to the expiration of your approval (which is one year from the date of the Chair’s signature below), you will be reminded to submit your renewal form along with any new changes or amendments you wish to make to your study. If there have been no major changes to your protocol, your approval may be renewed for another year.

Yours sincerely,

[Signature]
Chair, Research Ethics Board

[Date]

ORIGINAL TO INVESTIGATOR - COPY TO DEPARTMENT HEAD - COPY TO HOSPITALS/P&T (if appropriate) - FILE COPY

Study Code: PHE-089-09

➢ Investigators please note that if your trial is registered by the sponsor, you must take responsibility to ensure that the registration information is accurate and complete
APPENDIX C

Letter of Information and Consent Form
LETTER OF INFORMATION
& CONSENT FORM

School of Kinesiology and Health Studies
Physical Education Centre
Queen’s University

THE EFFECT OF SPORT CONFIDENCE ON DROP VERTICAL JUMP PERFORMANCE AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

Dear Subject,

You are invited to participate in a research study examining the effects of confidence on performance following anterior cruciate ligament (ACL) reconstruction surgery in athletes. This research study is being conducted by Robin Goody (Principal Investigator) and Dr. Patrick Costigan (Faculty Advisor). The following letter of information will be reviewed with you and the procedures of the study described to you in detail. Please feel free to ask questions at any time. This study has been reviewed for ethical compliance by the Queen’s University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board.

INVESTIGATORS:

Robin Goody 613-533-2658 (School of Kinesiology and Health Studies)
Dr. Patrick Costigan 613-533-6603 (School of Kinesiology and Health Studies)

DETAILS OF THE STUDY:

Purpose and Objectives of the Study

The purpose of this study is to determine if confidence affects performance in athletes who have had surgery on their ACL. The objectives of this study are two-fold; the first objective is to develop an equation that represents the relationship between drop vertical jump (DVJ) performance and physical attributes (anaerobic power, balance, calf girth, body fat and age) in a group of healthy subjects. The second objective is to apply this equation to a group of ACL reconstructed subjects to determine if the strength of the relationship is the same as for the healthy group and if the relationship is improved by including confidence (determined from a survey). It is hypothesized that by including confidence the equation will better predict the ACL subjects’ DVJ performance.
Procedures

You will wear shorts during testing. Your height and weight will be recorded. Your leg dominance will be determined by instructing you to perform three tasks: walk up stairs, kick a ball and stand on one lower extremity; the lower extremity used for two of the three tasks will be considered dominant. You will have the following measurements tested: anaerobic power, balance, calf girth, and body fat. You will also execute a series of drop vertical jumps (DVJ). Finally, you will complete a survey. The order of testing will be randomized and will alternate energy demanding measures with non-energy demanding measures to allow for adequate rest. The energy demanding measures include: anaerobic power, balance and DVJ; and the non-energy demanding measures include: calf girth, body fat and the survey. You will be asked to perform a short five minute warm-up on a treadmill before testing.

Physical Attributes

Anaerobic Power Test
You will complete the Margaria – Kalamen anaerobic power test. You will run up a set of stairs taking two steps at a time as fast as you can. A switch plate will be located on both the fourth and sixth steps that will start and stop a timer. The vertical distance between the fourth and sixth steps will be measured. You will be allowed to practice the task once and then perform the test three times with a 30 second rest period between trials. The fastest of the three trials will be used. (Davis et al., 2003; Margaria et al., 1966)

Stork Balance Test
You will stand on a mini-trampoline with one leg and your eyes closed. The time that you can stand without losing your balance (defined as the other leg touching down) will be measured. You will then take a 30 second rest and perform the task again with the opposite leg. This will be done twice per leg. The longer of the two trials per leg will be recorded. (Davis et al., 2003)

Calf Girth
You will lie down on your back and using a standard tape measure the calf girth will be measured at 10.2 cm below the inferior pole of the patella on both legs. (Davis et al., 2003)

Percent Body Fat
Body fat composition will be determined with a bioelectric impedance analyzer. You will lie down on your back with your arms slightly abducted from your body and your legs slightly separated. Surface electrodes will be placed on the right side of the body on the hands and feet. An appropriate equation will then be determined and applied to calculate the body fat composition. (Janssen et al., 2000; Lukaski, Bolonchuk, Hall, & Siders, 1986)

Drop Vertical Jump
You will be instrumented with a marker on both the left and right hip. A one second standing trial will be collected to determine your reference hip height. You will then stand on a 30cm high box. Many studies have used this height and higher for drop landing tasks and DVJ tasks with both ACL subjects and healthy subjects(Decker et al., 2002; Ortiz et al., 2008; Paterno et al., 2007; Vairo et al., 2008). You will drop directly down off the box and immediately jump as high as possible (Ford et al., 2005). You will perform five trials where the left foot is lifted first before dropping and five trials where the right foot is lifted first. The order will be randomly determined. You will be able to first practice the task and then perform a total of ten trials with 30 seconds of rest between each
trials will be repeated if they are non-acceptable (if you lose your balance, if your foot does not land on the proper spot, or if technical problems arise).

**Survey**

You will complete a survey. The survey for the control group will consist of demographic information and information regarding physical activity participation. The survey for the ACL group will consist of the same information in the control group’s survey as well as information pertaining to their surgery, current sport status and a 12-item ACL-Return to Sport after Injury (ACL-RSI) scale.

For each ACL-RSI questions you will be instructed to place a mark on the line that you think best describes you in relation to the two extremes (not at all or extremely). (Webster et al., 2008)

**Exclusion Criteria**

To minimize the risk of injury and reduce variation in the participant characteristics, subject selection will be limited to only healthy subjects for the control group and subjects who have had ACL surgery but are otherwise healthy for the experimental group. All subjects must be recreationally active by participating in sport and/or exercise 2-3 times/week for a total of 2-3 hours (minimum). Also an exclusion questionnaire will be completed by all subjects (with the exception of a question regarding reconstructive surgery for the ACL group). The subjects in the experimental group must have had unilateral ACL reconstructive surgery with either a patellar tendon or a hamstring tendon graft within the past five years. The ACL subjects must not have had any other surgical procedures performed during the reconstruction (ie. meniscus repair). Also the ACL subjects must have successfully completed their rehabilitation programs and be released to full participating in athletics by their physician.

**Statement of Risks Involved**

Discomfort or incapacity is minimal and only associated with the physical exertion involved in performing the anaerobic power test, balance test and drop vertical jumps. You will perform an adequate warm-up and will be provided with detailed instructions prior to performing the trials. There will also be ample opportunity for you to rest between trials. No long-term discomfort is expected. Also, during the physical exertion tasks you will be closely monitored to ensure your safety. Many studies have used the DVJ task and drop landing tasks at the same height (30 cm) and higher with both ACL subjects and healthy subjects (Decker et al., 2002; Ortiz et al., 2008; Paterno et al., 2007; Vairo et al., 2008). In the event that you are injured as a result of the study protocol, medical care will be provided to you until resolution of the medical problem. By signing this consent form, you do not waive your legal rights nor release the investigator(s).

**Expected Benefits**

While you may not benefit directly from this study, results from this study may improve the understanding of the characteristics that predict height in a DVJ task as well as the effects confidence has on DVJ performance and may benefit athletes in the future.

**Maintenance of Confidentiality**

All information obtained during the course of this study is strictly confidential and your anonymity will be protected at all times. Your identity is recorded only once by the researcher at the time of filing the participant's consent form. These files are accessible only to the principal investigator and faculty advisor. All participants are assigned a record number that is linked to this file. All data recorded in computer files contain this number, rather than your name. The written documents are kept in a secure location to which only the principal investigator and faculty advisor
have access and the computer files are kept on a password protected computer. In all cases of publication, only summary data are used and this is done in such a way that no individual can be identified.

**Right to Withdraw from the Study**

Your participation in this study is completely voluntary. Stopping the testing protocol will always be under your control. You may withdraw from this study at any time without penalty or coercion. Your data will be removed if you wish it to be withdrawn.

**Withdrawal of Subject by Principal Investigator**

You may be withdrawn from this study by the principal investigator if it is felt that you are unable to safely continue the session.
SUBJECT STATEMENT AND SIGNATURE:

As a volunteer participant, I have read and understand the consent form for this study. The purposes, procedures, and technical language have been explained to me. I have been given sufficient time to consider the above information and withdraw if I choose to do so. I have had the opportunity to ask questions which have been answered to my satisfaction. I understand that I can withdraw at any time. I am voluntarily signing this consent form below. I will receive a copy of this consent form for future reference.

If I am dissatisfied with any aspect of the study, or have questions, concerns or adverse events, I have been encouraged to contact:

Robin Goody (Principal Investigator) 613-533-2658
Dr. Patrick Costigan (School of Kinesiology and Health Studies, Director) 613-533-6603

If I have questions regarding my rights as a research subject I can contact:

Dr. Albert Clark (Research Ethics Board, Chair) 613-533-6081

(please sign and return this page ONLY to the researchers)

By signing this consent form, I am indicating that I agree to participate in this study.

__________________________________
Subject Code: _________
Print your Name

__________________________________
Signature of Subject

__________________________________
Signature of Witness

STATEMENT OF INVESTIGATOR:

I, or one of my colleagues, have carefully explained to the subject the nature of the above research study. I certify that, to the best of my knowledge, the subject understands clearly the nature of the study and demands, benefits, and risks involved to participants in this study.

__________________________________
Signature of Principal Investigator

78
APPENDIX D

Sample Size Calculations
For the sample size calculations the results from the Davis and colleagues’ (2003) study were used to determine an appropriate sample size for this study. Davis and colleagues (2003) found an adjusted $R^2$ value of 0.82 with five independent variables. Equation D1 from Portney & Watkins (2009) was used to calculate sample size.

\[
N = \frac{\lambda(1-R^2)}{R^2}
\]  
(D1)

Where $N$ = sample size; $\lambda$ = the index to which $R^2$ is converted that accounts for both the number of subjects and independent variables, based on power, independent variables and residual degrees of freedom and $R^2 = 0.82$ (Davis et al., 2003). Using Table C.8 from Portney & Watkins (2009) for determining values of $\lambda$, with the number of independent variables ($k$) being five, and residual degrees of freedom ($N-k-1$) being less than 60, and power being 0.80, $\lambda=14.0$. $N$ is therefore calculated to be 3.07. Rounding up 4 participants are needed.
APPENDIX E

Exclusion Questionnaire
Exclusion Questionnaire: Subject Code: _____

1. Do you have a chronic or painful condition in either lower extremity? □yes □no

2. Have you had a fracture in either of your lower extremities within the past year? □yes □no

3. Have you sustained a soft-tissue injury (muscle strain, ligament sprain, tendinitis, etc.) to either of your lower extremities within the last two years? □yes □no

4. If you have previously sustained a soft-tissue injury, does the injury currently impede participation in recreational activities? □yes □no

5. Have you sustained the same soft-tissue injury three times within the past year? □yes □no

6. Have you ever had lower back pain or pain extending into the legs resulting from a herniated disc? □yes □no

7. Have you ever had any reconstructive surgeries (ACL, ankle, knee)? □yes □no

8. Have you ever had any joint replacement surgeries (hip, knee)? □yes □no

9. Do you have any cardiovascular conditions (high blood pressure, heart disease, fainting, etc.) that limit your participation in physical activity? □yes □no
Table F1: ACL subjects’ information including date of injury, date of surgery, type of graft used, leg operated on, number of months of rehabilitation, clearance for sports participation and current sports status.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Date of Injury</th>
<th>Date of Surgery</th>
<th>Graft Used</th>
<th>Leg</th>
<th>No. of Months of Rehab</th>
<th>Cleared for Sports</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>May 2006</td>
<td>Aug 2006</td>
<td>Hamstring</td>
<td>Right</td>
<td>8</td>
<td>Yes</td>
<td>Returned to Sport</td>
</tr>
<tr>
<td>2</td>
<td>May 2007</td>
<td>Sept 2007</td>
<td>Hamstring</td>
<td>Left</td>
<td>6</td>
<td>Yes</td>
<td>Returned to Sport</td>
</tr>
<tr>
<td>3</td>
<td>Feb 2004</td>
<td>Aug 2004</td>
<td>Hamstring</td>
<td>Left</td>
<td>6</td>
<td>Yes</td>
<td>Returned to Sport</td>
</tr>
<tr>
<td>4</td>
<td>Oct 2005</td>
<td>Dec 2005</td>
<td>Hamstring</td>
<td>Left</td>
<td>8</td>
<td>Yes</td>
<td>Returned to Sport</td>
</tr>
<tr>
<td>5</td>
<td>May 2003</td>
<td>Nov 2005</td>
<td>Hamstring</td>
<td>Left</td>
<td>3</td>
<td>Yes</td>
<td>Returned to Sport</td>
</tr>
<tr>
<td>6</td>
<td>Aug 2006</td>
<td>May 2007</td>
<td>Hamstring</td>
<td>Left</td>
<td>6</td>
<td>Yes</td>
<td>Returned to Sport</td>
</tr>
<tr>
<td>7</td>
<td>Jan 2003</td>
<td>Nov 2005</td>
<td>Patellar</td>
<td>Left</td>
<td>3</td>
<td>Yes</td>
<td>Returned to Sport</td>
</tr>
<tr>
<td>8</td>
<td>Jun 2005</td>
<td>Apr 2006</td>
<td>Patellar</td>
<td>Right</td>
<td>4</td>
<td>Yes</td>
<td>Not Returned</td>
</tr>
<tr>
<td>9</td>
<td>Feb 2004</td>
<td>Sep 2005</td>
<td>Hamstring</td>
<td>Right</td>
<td>6</td>
<td>Yes</td>
<td>Returned to Sport</td>
</tr>
<tr>
<td>10</td>
<td>Jan 2006</td>
<td>Feb 2007</td>
<td>Hamstring</td>
<td>Right</td>
<td>3</td>
<td>Yes</td>
<td>Not Returned</td>
</tr>
<tr>
<td>11</td>
<td>Sep 2006</td>
<td>Sep 2006</td>
<td>Patellar</td>
<td>Right</td>
<td>6</td>
<td>Yes</td>
<td>Returned to Sport</td>
</tr>
<tr>
<td>12</td>
<td>July 2007</td>
<td>Aug 2007</td>
<td>Patellar</td>
<td>Left</td>
<td>9</td>
<td>Yes</td>
<td>Not Returned</td>
</tr>
<tr>
<td>13</td>
<td>Oct 2004</td>
<td>Dec 2004</td>
<td>Patellar</td>
<td>Left</td>
<td>6</td>
<td>Yes</td>
<td>Returned to Sport</td>
</tr>
</tbody>
</table>
APPENDIX G

Custom LabView Program
**Figure G1**: Image of the interface of the custom LabView program used as the timer for the anaerobic power test, where the timer started and stopped when contact was made with the first and second switch, respectively.
**Figure G2:** The block diagram of the custom LabView program, used as the timer for the anaerobic power test.
APPENDIX H

Paired T-Tests and Correlations

for Calf Girth, Thigh Girth and Knee Angle
**Table H1:** Paired t-test and correlation results for the control group with comparisons between left and right sides for calf girth, thigh girth and knee angle.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>Correlations</th>
<th>Paired Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std. Deviation</td>
<td>Std. Error Mean</td>
<td>r</td>
<td>Sig.</td>
</tr>
<tr>
<td>Pair 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.Calf</td>
<td>37.05</td>
<td>2.28</td>
<td>0.39</td>
<td>0.96</td>
<td>0.000</td>
</tr>
<tr>
<td>R.Calf</td>
<td>37.06</td>
<td>2.36</td>
<td>0.40</td>
<td>0.93</td>
<td>0.000</td>
</tr>
<tr>
<td>Pair 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.Thigh</td>
<td>51.49</td>
<td>3.80</td>
<td>0.64</td>
<td>0.91</td>
<td>0.000</td>
</tr>
<tr>
<td>R.Thigh</td>
<td>51.62</td>
<td>3.880</td>
<td>0.64</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pair 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.Knee.Ang</td>
<td>10.63</td>
<td>5.68</td>
<td>0.96</td>
<td>0.87</td>
<td>0.000</td>
</tr>
<tr>
<td>R.Knee.Ang</td>
<td>10.71</td>
<td>6.19</td>
<td>1.05</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table H2:** Paired t-test and correlation results for the ACL group with comparisons between left and right sides for calf girth, thigh girth and knee angle.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>Correlations</th>
<th>Paired Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std. Deviation</td>
<td>Std. Error Mean</td>
<td>r</td>
<td>Sig.</td>
</tr>
<tr>
<td>Pair 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.Calf</td>
<td>38.54</td>
<td>1.82</td>
<td>0.51</td>
<td>0.87</td>
<td>0.000</td>
</tr>
<tr>
<td>R.Calf</td>
<td>38.75</td>
<td>1.49</td>
<td>0.41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pair 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.Thigh</td>
<td>52.23</td>
<td>3.96</td>
<td>1.10</td>
<td>0.87</td>
<td>0.000</td>
</tr>
<tr>
<td>R.Thigh</td>
<td>54.27</td>
<td>3.68</td>
<td>1.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pair 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.Knee.Ang</td>
<td>8.38</td>
<td>6.51</td>
<td>1.81</td>
<td>0.82</td>
<td>0.001</td>
</tr>
<tr>
<td>R.Knee.Ang</td>
<td>10.15</td>
<td>5.87</td>
<td>1.63</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX I

Paired T-Tests and Correlations

for Body Fat Equations
Table I: Paired t-test and correlation results for the control group’s males with comparisons between the Tanita BC-418 equation and the equation developed by Sun and colleagues (2003).

<table>
<thead>
<tr>
<th>Pair 1</th>
<th>BF – Tanita</th>
<th>BF - Sun</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>Correlations</th>
<th>Paired Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>r</td>
<td>Sig.</td>
</tr>
<tr>
<td>BF – Tanita</td>
<td>13.97</td>
<td>4.33</td>
<td>1.02</td>
<td>0.997</td>
<td>0.00</td>
<td>93.15</td>
<td>17</td>
</tr>
<tr>
<td>BF - Sun</td>
<td>24.76</td>
<td>3.97</td>
<td>0.94</td>
<td>0.983</td>
<td>0.00</td>
<td>38.86</td>
<td>16</td>
</tr>
</tbody>
</table>

Table II: Paired t-test and correlation results for the control group’s females with comparisons between the Tanita BC-418 equation and the equation developed by Sun and colleagues (2003).

<table>
<thead>
<tr>
<th>Pair 1</th>
<th>BF – Tanita</th>
<th>BF - Sun</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>Correlations</th>
<th>Paired Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>r</td>
<td>Sig.</td>
</tr>
<tr>
<td>BF – Tanita</td>
<td>23.27</td>
<td>4.70</td>
<td>1.14</td>
<td>0.983</td>
<td>0.00</td>
<td>38.86</td>
<td>16</td>
</tr>
<tr>
<td>BF - Sun</td>
<td>31.37</td>
<td>4.72</td>
<td>1.15</td>
<td>0.983</td>
<td>0.00</td>
<td>38.86</td>
<td>16</td>
</tr>
</tbody>
</table>
APPENDIX J

Matlab DVJ Analysis Program
**Figure J1:** Flow chart of Matlab functions used to process the DVJs.
**Doall**

```matlab
function doall(group)
%function doall(group)
%group equals either n (for controls) or a (for acls)
%creates a file called Results and a file called Max
%runs dosubject on the group and put all the data in the Results file
%finds max jump height for each subject
%puts that height and the related info into the Max file

nskiplist=[5 19 28];
hcol=5;

filename='C:\Thesis\data\Results.csv';

fid=fopen(filename,'w');
fclose(fid);

fid=fopen(filename,'a');

filename='C:\Thesis\data\Max.csv';

fidmax=fopen(filename,'w');
fclose(fidmax);

fidmax=fopen(filename,'a');

if group=='n';
  for i=1:38
    ok=1;
    for j=1:length(nskiplist)
      if i==nskiplist(j)
        ok=0;
      end;
    end;
  end;

  if ok
    sid=num2str(i,'%02.f');
    fullid=['n' sid]
    nsubject=dosubject(fullid);
    [nrows, ncolumns]=size(nsubject);
    max=nsubject(1,hcol);
    maxtrial=1;
    for t=1:nrows
      if nsubject(t,hcol)>max
        max=nsubject(t,hcol);
        maxtrial=t;
      end
    end
  end
```
for j=1:nrows
    fprintf(fid,"%d,%d,%d,%d,%6.1f,%6.1f \n",
    nsubject(j,1),nsubject(j,2),nsubject(j,3),nsubject(j,4),nsubject(j,5),nsubject(j,6));
end;

fprintf(fidmax,"%d,%d,%d,%d,%6.1f,%6.1f \n",
    nsubject(maxtrial,1),nsubject(maxtrial,2),nsubject(maxtrial,3),nsubject(maxtrial,4),nsubject(maxtrial,5),
    nsubject(maxtrial,6));
end;
end;

else
for i=01:13
    sid=num2str(i,"%02.f");
    fullid=['a' sid]
    asubject=dosubject(fullid);
    [arows, acolumns]=size(asubject);

    max=asubject(1,hcol);
    maxtrial=1;
    for t=1:arows
        if asubject(t,hcol)>max
            max=asubject(t,hcol);
            maxtrial=t;
        end
    end

    for j=1:arows
        fprintf(fid,"%d,%d,%d,%d,%6.1f,%6.1f \n",
            asubject(j,1),asubject(j,2),asubject(j,3),asubject(j,4),asubject(j,5),asubject(j,6));
    end;

    fprintf(fidmax,"%d,%d,%d,%d,%6.1f,%6.1f \n",
            asubject(maxtrial,1),asubject(maxtrial,2),asubject(maxtrial,3),asubject(maxtrial,4),asubject(maxtrial,5),
            asubject(maxtrial,6));
    end;
end;
end;
fclose(fid);
fclose(fidmax);
Dosubject

function [subjectdata] = dosubject(subjectid);

%function [subjectdata] = dosubject(subjectid);
%subjectid = 3 character subject id
%identify the base files (standing rest trial) and runs getbaseline for both the 1st file and the 7th file
%dojump will run for each trial number (2-6 and 8-12)
%the output is a matrix (6 columns) that contains the following:
%1. snum = the subject number
%2. normal = assigns a value of 1 for normals and 0 for ACLrs
%3. i = jump number (1-10)
%4. leg = assigns a value of 1 for right and 0 for left
%5. jumphgt = the max jump height
%6. minhip = the min hip depth

trialnum = ['002'; '003'; '004'; '005'; '006'; '008'; '009'; '010'; '011'; '012'];
trialnum2 = ['002'; '003'; '004'; '005'; '006'; '007'; '008'; '009'; '010'; '011'];

subnum2 = ['n01n02n03n25'];

base = ['C:\Thesis\data\', subjectid, '\converted\LCA001.', subjectid];
basehgt = getbaseline(base);

scode = subjectid(1:2:3);
snum = str2num(scode);

if lower(subjectid(1)) == 'n'
    normal = 1;
else
    normal = 0;
end;

for i = 1:5
    trial = ['C:\Thesis\data\', subjectid, '\converted\LCA', trialnum(i,:), '.', subjectid];
    [minhip, jumphgt, leg] = dojump(basehgt, trial);
    fprintf('subject: %s, trial: %s
', subjectid, trialnum(i,:));

    subjectdata(i, 1) = snum;
    subjectdata(i, 2) = normal;
    subjectdata(i, 3) = i;
    subjectdata(i, 4) = leg;
    subjectdata(i, 5) = jumphgt;
    subjectdata(i, 6) = minhip;
end;

isgood = findstr(subjectid, subnum2);
if length(isgood) == 0
    base = ['C:\Thesis\data\', subjectid, '\converted\LCA007.', subjectid];
end;
basehgt=getbaseline(base);

for i=6:10
    trial=['C:\Thesis\data\',subjectid,'\converted\LCA',trialnum(i,:),',',subjectid];
    [minhip,jumphgt,leg]=dojump(basehgt,trial);

    fprintf('subject: %s, trial: %s 
', subjectid, trialnum(i,:));
    subjectdata(i,1)=snum;
    subjectdata(i,2)=normal;
    subjectdata(i,3)=i;
    subjectdata(i,4)=leg;
    subjectdata(i,5)=jumphgt;
    subjectdata(i,6)=minhip;
end;
else
    base=['C:\Thesis\data\',subjectid,'\converted\LCA007.',subjectid];

    basehgt=getbaseline2(base);

    for i=6:10
        trial=['C:\Thesis\data\',subjectid,'\converted\LCA',trialnum2(i,:),',',subjectid];
        [minhip,jumphgt,leg]=dojump(basehgt,trial);

        fprintf('subject: %s, trial: %s 
', subjectid, trialnum2(i,:));
        subjectdata(i,1)=snum;
        subjectdata(i,2)=normal;
        subjectdata(i,3)=i;
        subjectdata(i,4)=leg;
        subjectdata(i,5)=jumphgt;
        subjectdata(i,6)=minhip;
    end;
end;
**Dojump**

```matlab
function [minhip,jumphgt,leg] = dojump(baseline,filename)
%function [minhip,jumphgt,leg] = dojump(baseline,filename)
%baseline=mean hip height in a standing trial
%filename=name of the trial
%runs getdz to give z=vertical markers path during jump
%runs getmaxheight on z to give jumphgt
%finds the minimum value in z to give minhip
%runs getleg to determine if it was right=1 or left=0
%function returns minhip, jumphgt and leg

z=getdz(baseline,filename);

jumphgt=getmaxheight(z);

minhip=getminlocandvalue(z);

leg=getleg(filename);
```

**Getbaseline**

```matlab
function [baseline]=getbaseline(filename)
%[baseline]=getbaseline(filename)
%loads rest trial and calculates the mean of the vertical marker

data = dlmread(filename);

baseline=mean(data(:,2));
```

**Getdz**

```matlab
function [z]=getdz(restmean,rawfilename)
%[z]=getdz(restmean,rawfilename)
% restmean= baseline (which is found by using the function getbaseline)
% rawfilename= name of the jump file
% loads the jump file and takes out the vertical marker displacement
% then removes the baseline
% and finally flips the data

raw = dlmread(rawfilename);

z=raw(:,2);

z=z-restmean;

z=z.^-1;
```
Getmaxheight
function [value]=getmaxheight (z);
% value=getmaxheight (z)
% assigns the value 1 to the locations where z is less than zero
% finds the locations of all the nonzeros (1s)
% finds the max value from the location that was just found to the end

iszero=z<0;
zeroloc=find(iszero);
value=max(z(zeroloc(1):350));

Getmin
function [value]=getmin(z);
%function [value]=getmin(z);
%finds the first point where z is less than zero
%that location is loc1
%finds the first point after loc1 that is greater than zero
%this point is added on to loc1 to get loc2
%the function then searches for the minimum value between loc1 and loc2
%this ensures that the minimum vale is from the first valley (hip depth)

iszero=z<0;
zeroloc=find(iszero);
loc1=zeroloc(1);
iszero2=z((loc1+2):350)>0;
zeroloc2=find(iszero2);
if length(zeroloc2)<10
    loc2=400;
    fprintf('could not find loc2 
');
else
    loc2=zeroloc2(1)+loc1;
end
value=min(z(loc1:loc2));
function leg=getleg(trialname);
%function leg=getleg(trialname)
%reads in the raw trial and extracts the x values
%compares a value at point 10 to a value at point 350
%if the value at 10 is bigger than the value at 350 = right side (1)
%and the opposite = left side (0)

raw = dlmread(trialname);
x=raw(:,1);

xstart=x(10);
xstop=x(350);

if (xstart > xstop)
    leg=1;
else
    leg=0;
end;
APPENDIX K

ACL-Return to Sport after Injury Scale
ACL-Return to Sport after Injury (ACL-RSI) scale

Subject Code: _____

Instructions: Place a mark on the line, which best describes you in relation to the two descriptors.

1. Are you confident that you can perform at your previous level of sport participation?
   
   
   0  1  2  3  4  5  6  7  8  9  10
   
   not at all          extremely

2. Do you think you are likely to re-injury your knee by participating in your sport?
   
   
   10  9  8  7  6  5  4  3  2  1  0
   
   not at all          extremely

3. Are you nervous about playing your sport?
   
   
   10  9  8  7  6  5  4  3  2  1  0
   
   not at all          extremely

4. Are you confident that your knee will not give way by playing your sport?
   
   
   0  1  2  3  4  5  6  7  8  9  10
   
   not at all          extremely
5. Are you confident that you could play your sport without concern for your knee?

6. Do you find it frustrating to have to consider your knee with respect to your sport?

7. Are you fearful of re-injuring your knee by playing your sport?

8. Are you confident about your knee holding up under pressure?

9. Are you afraid of accidentally injuring your knee by playing your sport?
10. Do thoughts of having to go through surgery and rehabilitation again prevent you from playing your sport?

[10-point scale from not at all to extremely]

11. Are you confident about your ability to perform well at your sport?

[10-point scale from not at all to extremely]

12. Do you feel relaxed about playing your sport?

[10-point scale from not at all to extremely]
APPENDIX L

Multicollinearity Statistics
Table L1: Multicollinearity statistics, tolerance and variance inflation factor (VIF) for models 1-9.

<table>
<thead>
<tr>
<th>Model</th>
<th>Variables</th>
<th>Tolerance</th>
<th>VIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>%SM</td>
<td>0.76</td>
<td>1.30</td>
</tr>
<tr>
<td></td>
<td>Power</td>
<td>0.76</td>
<td>1.30</td>
</tr>
<tr>
<td>2</td>
<td>%SM</td>
<td>0.79</td>
<td>1.27</td>
</tr>
<tr>
<td></td>
<td>Power</td>
<td>0.79</td>
<td>1.27</td>
</tr>
<tr>
<td>3</td>
<td>%SM</td>
<td>0.73</td>
<td>1.38</td>
</tr>
<tr>
<td></td>
<td>Power</td>
<td>0.73</td>
<td>1.38</td>
</tr>
<tr>
<td></td>
<td>Survey</td>
<td>0.76</td>
<td>1.32</td>
</tr>
<tr>
<td>4</td>
<td>Power</td>
<td>0.37</td>
<td>1.68</td>
</tr>
<tr>
<td></td>
<td>Weight</td>
<td>0.37</td>
<td>1.72</td>
</tr>
<tr>
<td></td>
<td>Knee Angle</td>
<td>0.96</td>
<td>1.04</td>
</tr>
<tr>
<td>5</td>
<td>Weight</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>Weight</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>Weight</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>Weight</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>Weight</td>
<td>0.95</td>
<td>1.06</td>
</tr>
<tr>
<td></td>
<td>Survey</td>
<td>0.95</td>
<td>1.06</td>
</tr>
</tbody>
</table>
APPENDIX M

Actual, Predicted and Residual Values

for Power Models in the ACL Group
Table M1: Actual, predicted and residual values for the ACL group using Model 8: power = -41.07 + 1.89weight, and Model 9: power = -54.48 + 1.78weight +0.33survey.

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Actual</th>
<th>Power = Weight Predicted</th>
<th>Power = Weight + Survey Predicted</th>
<th>Residual</th>
<th>Power = Weight + Survey Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>87.73</td>
<td>94.31</td>
<td>95.02</td>
<td>-6.58</td>
<td>-7.29</td>
</tr>
<tr>
<td>2</td>
<td>130.97</td>
<td>119.30</td>
<td>121.27</td>
<td>11.66</td>
<td>9.70</td>
</tr>
<tr>
<td>3</td>
<td>99.40</td>
<td>104.72</td>
<td>108.64</td>
<td>-5.33</td>
<td>-9.25</td>
</tr>
<tr>
<td>4</td>
<td>70.84</td>
<td>73.10</td>
<td>72.34</td>
<td>-2.26</td>
<td>-1.49</td>
</tr>
<tr>
<td>5</td>
<td>102.80</td>
<td>91.85</td>
<td>90.52</td>
<td>10.95</td>
<td>12.28</td>
</tr>
<tr>
<td>6</td>
<td>141.69</td>
<td>149.98</td>
<td>142.22</td>
<td>-8.28</td>
<td>-0.52</td>
</tr>
<tr>
<td>7</td>
<td>71.90</td>
<td>75.75</td>
<td>86.84</td>
<td>-3.85</td>
<td>-14.94</td>
</tr>
<tr>
<td>8</td>
<td>65.96</td>
<td>55.68</td>
<td>59.49</td>
<td>10.28</td>
<td>6.47</td>
</tr>
<tr>
<td>9</td>
<td>120.11</td>
<td>148.08</td>
<td>152.03</td>
<td>-27.97</td>
<td>-31.92</td>
</tr>
<tr>
<td>10</td>
<td>78.61</td>
<td>103.21</td>
<td>83.47</td>
<td>-24.60</td>
<td>-4.87</td>
</tr>
<tr>
<td>11</td>
<td>163.03</td>
<td>130.66</td>
<td>136.60</td>
<td>32.37</td>
<td>26.44</td>
</tr>
<tr>
<td>12</td>
<td>72.37</td>
<td>76.70</td>
<td>69.58</td>
<td>-4.34</td>
<td>2.78</td>
</tr>
<tr>
<td>13</td>
<td>167.93</td>
<td>149.98</td>
<td>155.32</td>
<td>17.96</td>
<td>12.62</td>
</tr>
</tbody>
</table>
APPENDIX N

Correlations
Table N1: Pearson correlation coefficients for the control group’s data for the following variables: weight, knee angle, power, % body fat, body fat mass, % skeletal muscle, skeletal muscle mass, and DVJ height. * denotes significance with p<0.05.

<table>
<thead>
<tr>
<th></th>
<th>Weight</th>
<th>Knee Angle</th>
<th>Power</th>
<th>% Body Fat</th>
<th>Body Fat Mass</th>
<th>% Skeletal Muscle</th>
<th>Skeletal Muscle Mass</th>
<th>DVJ Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td></td>
<td>-0.01</td>
<td>0.90*</td>
<td>-0.15</td>
<td>0.37*</td>
<td>0.23</td>
<td>0.83*</td>
<td>0.42*</td>
</tr>
<tr>
<td>Knee Angle</td>
<td>-0.01</td>
<td></td>
<td>-0.09</td>
<td>0.16</td>
<td>0.15</td>
<td>-0.15</td>
<td>-0.10</td>
<td>0.09</td>
</tr>
<tr>
<td>Power</td>
<td>0.90*</td>
<td>-0.09</td>
<td></td>
<td>-0.41*</td>
<td>0.07</td>
<td>0.49*</td>
<td>0.91*</td>
<td>0.64*</td>
</tr>
<tr>
<td>% Body Fat</td>
<td>-0.15</td>
<td>0.16</td>
<td></td>
<td>-0.41*</td>
<td></td>
<td>0.86*</td>
<td>-0.98*</td>
<td>-0.66*</td>
</tr>
<tr>
<td>Body Fat Mass</td>
<td>0.37*</td>
<td>0.15</td>
<td>0.07</td>
<td>0.86*</td>
<td></td>
<td>-0.80*</td>
<td>-0.21</td>
<td>-0.40*</td>
</tr>
<tr>
<td>% Skeletal Muscle</td>
<td>0.23</td>
<td>-0.15</td>
<td>0.49*</td>
<td>-0.98*</td>
<td>-0.21</td>
<td></td>
<td>0.73*</td>
<td>0.68*</td>
</tr>
<tr>
<td>Skeletal Muscle Mass</td>
<td>0.83*</td>
<td>-0.10</td>
<td>0.91*</td>
<td>-0.66*</td>
<td>-0.80*</td>
<td>0.73*</td>
<td></td>
<td>0.68*</td>
</tr>
<tr>
<td>DVJ Height</td>
<td>0.42*</td>
<td>0.09</td>
<td>0.64*</td>
<td>-0.65*</td>
<td>-0.40*</td>
<td>0.69*</td>
<td>0.68*</td>
<td></td>
</tr>
</tbody>
</table>
Table N2: Pearson correlation coefficients for the ACL group’s data for the following variables: weight, knee angle, power, % body fat, body fat mass, % skeletal muscle, skeletal muscle mass, survey and DVJ height. * denotes significance with p<0.05.

<table>
<thead>
<tr>
<th></th>
<th>Weight</th>
<th>Knee Angle</th>
<th>Power</th>
<th>% Body Fat</th>
<th>Body Fat Mass</th>
<th>% Skeletal Muscle</th>
<th>Skeletal Muscle Mass</th>
<th>Survey</th>
<th>DVJ Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td></td>
<td>-0.43</td>
<td>0.89*</td>
<td>-0.17</td>
<td>0.52</td>
<td>0.18</td>
<td>0.89*</td>
<td>0.23</td>
<td>0.56*</td>
</tr>
<tr>
<td>Knee Angle</td>
<td>-0.43</td>
<td></td>
<td>-0.46</td>
<td>0.54</td>
<td>0.19</td>
<td>-0.48</td>
<td>0.57*</td>
<td>-0.60*</td>
<td>-0.34</td>
</tr>
<tr>
<td>Power</td>
<td>0.89*</td>
<td>-0.46</td>
<td></td>
<td>-0.43</td>
<td>0.20</td>
<td>0.46</td>
<td>0.94*</td>
<td>0.42</td>
<td>0.78*</td>
</tr>
<tr>
<td>% Body Fat</td>
<td>-0.17</td>
<td>0.54</td>
<td>-0.43</td>
<td></td>
<td>0.75*</td>
<td>-0.99*</td>
<td>-0.59*</td>
<td>-0.42</td>
<td>-0.39</td>
</tr>
<tr>
<td>Body Fat Mass</td>
<td>0.52</td>
<td>0.19</td>
<td>0.20</td>
<td>0.75*</td>
<td></td>
<td>-0.73*</td>
<td>0.09</td>
<td>-0.22</td>
<td>0.03</td>
</tr>
<tr>
<td>% Skeletal Muscle</td>
<td>0.18</td>
<td>-0.48</td>
<td>0.46</td>
<td>-0.99*</td>
<td>-0.73*</td>
<td></td>
<td>0.60*</td>
<td>0.42</td>
<td>0.44</td>
</tr>
<tr>
<td>Skeletal Muscle Mass</td>
<td>0.89*</td>
<td>0.94*</td>
<td>0.94*</td>
<td>-0.59*</td>
<td>0.09</td>
<td>0.61*</td>
<td>0.39</td>
<td>0.67*</td>
<td></td>
</tr>
<tr>
<td>Survey</td>
<td>0.23</td>
<td>0.42</td>
<td>0.42</td>
<td>-0.42</td>
<td>0.22</td>
<td>0.42</td>
<td>0.39</td>
<td>0.56*</td>
<td></td>
</tr>
<tr>
<td>DVJ Height</td>
<td>0.56*</td>
<td>-0.34</td>
<td>0.78*</td>
<td>-0.39</td>
<td>0.03</td>
<td>0.44</td>
<td>0.67*</td>
<td>0.56*</td>
<td></td>
</tr>
</tbody>
</table>
Table N3: Pearson correlation coefficients for the control group females’ data for the following variables: weight, knee angle, power, % body fat, body fat mass, % skeletal muscle, skeletal muscle mass, and DVJ height. * denotes significance with p<0.05.

<table>
<thead>
<tr>
<th></th>
<th>Weight</th>
<th>Knee Angle</th>
<th>Power</th>
<th>% Body Fat</th>
<th>Body Fat Mass</th>
<th>% Skeletal Muscle</th>
<th>Skeletal Muscle Mass</th>
<th>DVJ Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>0.14</td>
<td>0.84*</td>
<td>0.77*</td>
<td>0.88*</td>
<td>-0.79*</td>
<td>0.69*</td>
<td>-0.05</td>
<td></td>
</tr>
<tr>
<td>Knee Angle</td>
<td>0.14</td>
<td>0.04</td>
<td>0.04</td>
<td>0.06</td>
<td>-0.06</td>
<td>0.18</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>0.84*</td>
<td>0.04</td>
<td>0.65*</td>
<td>0.74*</td>
<td>-0.65*</td>
<td>0.59*</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>% Body Fat</td>
<td>0.77*</td>
<td>0.04</td>
<td>0.65*</td>
<td>0.97*</td>
<td>-0.98*</td>
<td>0.10</td>
<td>-0.17</td>
<td></td>
</tr>
<tr>
<td>Body Fat Mass</td>
<td>0.88*</td>
<td>0.06</td>
<td>0.74*</td>
<td>0.97*</td>
<td>-0.96*</td>
<td>0.27</td>
<td>-0.11</td>
<td></td>
</tr>
<tr>
<td>% Skeletal Muscle</td>
<td>-0.79*</td>
<td>-0.06</td>
<td>-0.65*</td>
<td>-0.98*</td>
<td>-0.96*</td>
<td>-0.11</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Skeletal Muscle Mass</td>
<td>0.69*</td>
<td>0.18</td>
<td>0.59*</td>
<td>0.10</td>
<td>0.27</td>
<td>-0.11</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>DVJ Height</td>
<td>-0.05</td>
<td>0.32</td>
<td>0.05</td>
<td>-0.17</td>
<td>-0.11</td>
<td>0.15</td>
<td>0.05</td>
<td></td>
</tr>
</tbody>
</table>
Table N4: Pearson correlation coefficients for the control group males’ data for the following variables: weight, knee angle, power, % body fat, body fat mass, % skeletal muscle, skeletal muscle mass, and DVJ height. * denotes significance with p<0.05.

<table>
<thead>
<tr>
<th></th>
<th>Weight</th>
<th>Knee Angle</th>
<th>Power</th>
<th>% Body Fat</th>
<th>Body Fat Mass</th>
<th>% Skeletal Muscle</th>
<th>Skeletal Muscle Mass</th>
<th>DVJ Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td></td>
<td>0.16</td>
<td>0.79*</td>
<td>0.74*</td>
<td>0.92*</td>
<td>-0.77*</td>
<td>0.77*</td>
<td>-0.50*</td>
</tr>
<tr>
<td>Knee Angle</td>
<td>0.16</td>
<td></td>
<td>0.21</td>
<td>0.07</td>
<td>0.16</td>
<td>0.02</td>
<td>0.20</td>
<td>0.34</td>
</tr>
<tr>
<td>Power</td>
<td>0.79*</td>
<td>0.21</td>
<td></td>
<td>0.60*</td>
<td>0.73*</td>
<td>-0.63*</td>
<td>0.59*</td>
<td>-0.06</td>
</tr>
<tr>
<td>% Body Fat</td>
<td>0.74*</td>
<td>0.07</td>
<td>0.59*</td>
<td></td>
<td>0.94*</td>
<td>-0.98*</td>
<td>0.16</td>
<td>-0.36</td>
</tr>
<tr>
<td>Body Fat Mass</td>
<td>0.92*</td>
<td>0.16</td>
<td>0.73*</td>
<td>0.94*</td>
<td></td>
<td>-0.94*</td>
<td>0.47</td>
<td>-0.44</td>
</tr>
<tr>
<td>% Skeletal Muscle</td>
<td>-0.77*</td>
<td>0.02</td>
<td>-0.63*</td>
<td>-0.98*</td>
<td>-0.94*</td>
<td></td>
<td>-0.19</td>
<td>0.39</td>
</tr>
<tr>
<td>Skeletal Muscle Mass</td>
<td>0.77*</td>
<td>0.20</td>
<td>0.59*</td>
<td>0.16</td>
<td>0.47</td>
<td>-0.19</td>
<td>-0.41</td>
<td></td>
</tr>
<tr>
<td>DVJ Height</td>
<td>-0.50*</td>
<td>0.34</td>
<td>-0.06</td>
<td>-0.36</td>
<td>-0.44</td>
<td>0.39</td>
<td>-0.41</td>
<td></td>
</tr>
</tbody>
</table>