AN INVESTIGATION OF OFF-ICE STRENGTH AND POWER MEASURES AMONG PRE-ELITE TO ELITE FIGURE SKATERS: PREDICTABILITY OF ON-ICE JUMP PERFORMANCE

by

ELIZABETH LYNNE HEIL

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This thesis for the Master of Sciences in Sports Medicine degree by

Elizabeth Lynne Heil

is approved for the Department for Health Sciences

by

_________________________________
Dr. Craig Elder, Chair

_________________________________
Dr. Jay Dawes, Committee Member

_________________________________
Dr. Amanda Elder, Committee Member

_________________________________
Dr. Steven Tragresser, Committee Member

_________________________________
Date

iii
ABSTRACT

Background. The evidence suggests off-ice training as a viable mechanism to improve on-ice jump performance; however, research is lacking conserving the collective predictability of strength and power measures in figure skater’s on-ice jump performance. Purpose. The purpose of this study was to investigate the relationship of off-ice strength and power and on-ice figure skating jump performance. Methods. A cross-sectional study design examined off-ice strength and power measures of nine competitive pre-elite to elite female skaters (14.3±1.8 years; 158.5±5.0cm; 48.9±7.16kg) and predictability of these variables to on-ice jump performance, over two testing sessions. Off-ice variables included vertical jump analysis via a force plate, long jump, S.T.A.R.S. tuck jump test, and backward overhead toss for distance. On-ice jump performance variables were derived via single axel jump analyses. Statistical analysis included multiple regression and Pearson’s correlations, with significance set at p < 0.05. Results. Mean on-ice axel jump performance: flight time 0.398±0.03sec, vertical jump height 27.9±3.9cm, and peak power 2,011.2±394.1watts. When comparing off-ice vertical jump flight-time and the S.T.A.R.S. tuck jump assessment, off-ice vertical jump flight-time was the top predictor of on-ice jump performance and accounted for 2-24.5% of the variances in the on-ice jump performance variables. However, these predictors were not statistically significant (p ≥ 0.05). A strong (r=0.60-0.79) negative, correlation was found between the age that figure skaters started skating and their height (p = ≤ 0.5) with their on-ice jump flight-time. Conclusion. The S.T.A.R.S. tuck jump assessment may be an off-ice testing measure that can use to assess strength and conditioning. The age that a figure skater begins skating and their current height may be factors affecting
their on-ice jump flight-times. The small sample size of this study did not allow results to be implied to the larger figure skating population; thus, the correlation of on-ice variables and predictability of off-ice strength and power measures warrant further research.

**Practical application.** The S.T.A.R.S. tuck jump assessment may be a test that can be used as a progress assessment for strength and conditioning programs, and possibly indicate if the training program is having an impact on on-ice jump performance.

**Key Words:** strength and conditioning, vertical jump height, figure skating, flight time, power
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# TABLE OF CONTENTS

## CHAPTER

I. INTRODUCTION ................................................................................................................. 1

  - Purpose of the Study ................................................................................................. 2

  - Research Questions ................................................................................................. 3

  - Hypothesis ................................................................................................................ 3

  - Strengths and Weaknesses ...................................................................................... 3

  - Limitations ............................................................................................................... 4

  - Assumptions ............................................................................................................. 4

  - Key Definitions ....................................................................................................... 5

II. LITERATURE REVIEW .................................................................................................... 7

  - Figure Skating .......................................................................................................... 7

  - Jump Performance Variables ................................................................................. 12

  - Off-ice Strength and Power ..................................................................................... 14

  - Summary .................................................................................................................. 16

III. METHODOLOGY ........................................................................................................... 17

  - Introduction ............................................................................................................. 17

  - Research Design ..................................................................................................... 17

  - Participants .............................................................................................................. 18

  - Off-ice Measurements ............................................................................................. 19

  - Independent Variables ........................................................................................... 20

  - On-ice Measurements .............................................................................................. 23

  - Dependent Variables ............................................................................................... 25

  - Data Collection ........................................................................................................ 26

  - Statistical Analysis ................................................................................................. 26

IV. MANUSCRIPT .............................................................................................................. 28

  - Introduction ............................................................................................................. 28

  - Methodology .......................................................................................................... 30

  - Results ...................................................................................................................... 35

  - Discussion ................................................................................................................ 40
<table>
<thead>
<tr>
<th>Conclusion</th>
<th>47</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practical Applications</td>
<td>47</td>
</tr>
<tr>
<td>REFFERENCES</td>
<td>49</td>
</tr>
<tr>
<td>APPENDICES</td>
<td>52</td>
</tr>
<tr>
<td>A. Informed Consent Adult</td>
<td>52</td>
</tr>
<tr>
<td>B. Informed Consent Child</td>
<td>55</td>
</tr>
<tr>
<td>C. Assent</td>
<td>58</td>
</tr>
<tr>
<td>D. Flyer</td>
<td>59</td>
</tr>
<tr>
<td>E. Data Collection Form</td>
<td>60</td>
</tr>
<tr>
<td>F. Questionnaire</td>
<td>61</td>
</tr>
<tr>
<td>G. Letter of Access</td>
<td>65</td>
</tr>
<tr>
<td>H. PARQ Ages 8-14</td>
<td>66</td>
</tr>
<tr>
<td>I. PARQ Ages 15+</td>
<td>68</td>
</tr>
<tr>
<td>J. Institutional Review Board Approval</td>
<td>69</td>
</tr>
</tbody>
</table>
TABLES

1. Descriptive Statistics for Figure Skaters .......................................................... 36
2. Descriptive Statistics for On-ice Jump Performance........................................ 36
3. Descriptive Statistics for Off-ice Variables....................................................... 37
4. Off-ice Vertical Jump Variable Comparison.................................................... 38
5. Pearson Correlation Coefficients of Participants On-ice Testing Variables ... 38
6. Pearson Correlation Coefficients of Off-ice and On-ice Testing Variables.... 39
7. Order of Ranking of the Best Predictors of On-ice Jump Performance ....... 40
FIGURES

1. LED Placement................................................................. 24
CHAPTER 1

INTRODUCTION

The sport of figure skating has evolved over time, with competitive focus shifting from control and flow to difficulty and precision.\textsuperscript{1} In the men’s and lady’s single event, competitive success has become more dependent on the increasing difficulty of jumps.\textsuperscript{1–3} With an added focus on technical difficulty, coaches and figure skaters allocate a large proportion of practice time to perfecting jump technique and increasing jump flight-times.\textsuperscript{4}

Repetitive jumps play a large role in a figure skater’s practice routine. In a study performed by Bruening and Richards,\textsuperscript{5} figure skaters were found to perform up to 50-100 on-ice jumps each day that they practiced. Both on-ice and off-ice jump training procedures are currently used to increase jump performance among figure skaters. Figure skaters typically train on-ice using jump drills and by attempting to perform un-mastered jumps, often resulting in falls.\textsuperscript{6} Alternatively, some figure skaters utilize off-ice jumping training, which may decrease the chance for injuries caused by repeated falling on ice due to un-mastered jumps.\textsuperscript{6} Off-ice strength and power training may help to increase lower body strength and power measure in figures skaters\textsuperscript{7} which could translate to an increase in on-ice jump performance. The struggle to maintain or gain performance levels and mitigate injury may be directly affected by the amount of time figure skaters spend off-ice training.\textsuperscript{7–11} Therefore, off-ice training may be a key component in extending the overall longevity of a figure skater’s career.
Off-ice strength and power training has been suggested as a way to improve a figure skater’s jump performance.\textsuperscript{6,7,9,12} This method of training may help increase the explosiveness of jump takeoffs by improving lower body strength, and may also give figure skaters the ability to complete more technical jumps, such as those with quadruple revolutions.\textsuperscript{2,9} On-ice jump height has been shown to correlate with upper and lower body strength measures amongst figure skaters.\textsuperscript{7} To date, the relationship of power measures and jump performance has only once been researched in teams of synchronized figure skaters.\textsuperscript{8}

The predictability of strength and/or power measurements on jump performance has yet to be studied in figure skaters. To date, there have been limited studies investigating the predictability of off-ice measures to on-ice jump performance. Podolsky, et al\textsuperscript{9} found a significantly positive correlation between upper and lower body strength measurements and on-ice jump height. Results indicated that muscle mass of the shoulders, knees, and hips were significantly correlated to the height of the on-ice single axel jump. In a study of synchronized figure skaters, off-ice measures of the slide board and vertical jump height correlated to skater’s on-ice speed and acceleration.\textsuperscript{13} Additionally, Hunnicut et al\textsuperscript{8} studied the effect of a low to moderate plyometric training program and found increased on-ice flight-times, off-ice vertical jump heights, and off-ice standing long jumps in synchronized figure skaters. This limited research indicates that additional investigation is warranted to investigate the predictability of off-ice strength and power measurements to on-ice jump performance among figure skaters.

**Purpose of the Study**
The evidence suggests off-ice training as a viable mechanism to improve on-ice jump performance\textsuperscript{5-8} however, there is a lack of research investigating the predictability of strength and/or power measures in single figure skaters on-ice jump performance. Therefore, the purpose of this study was to investigate off-ice strength and power measures among pre-elite to elite figure skaters and the predictability of on-ice jump performance. This study also aimed to help establish a scientific basis for the need of off-ice strength and power training as it relates to on-ice figure skating jump performance.

**Research Question**

Are figure skater’s off-ice lower body strength and endurance and upper and lower body power measures predictors of their on-ice jump performances? The more specific research questions that were answered through this study are:

1) How well do the off-ice performance testing variables of vertical jump height, flight time, peak power, vertical velocity, GRF, long jump, S.T.A.R.S tuck jump, and overhead toss predict on-ice jump performance variables of vertical jump height, peak power, and flight time?

2) How much variance in the on-ice jump performance variables can be explained by all of the different off-ice variables?

3) What are the relationships between off-ice performance testing variables and on-ice jump performance variables?

**Hypothesis**
**Null:** There will be no significant predictors of figure skater’s on-ice jump flight-time, vertical jump distances, and on-ice vertical jump peak power measures from off-ice strength and power measures.

**Strengths and Weaknesses**

Strengths of this study are the previously validated testing measures that were utilized to gather off-ice and on-ice performance test measures and the gathering of possible confounding variables through a participant survey. Weaknesses of this study include the possibility of a biased sample, as figure skating is an individual-based sport and recruiting a large sample of participants was difficult. The use of a volunteer sample took place, which weakens the ability to generalize the results of this study to the larger figure skating population.

**Limitations**

With the individualized nature of figure skating, availability and the recruitment of participants was the most limiting factor to this study. Results from this study specifically pertain to figure skaters from the 7K international skating club. Recruitment of participants was limited to coaches who allow their figure skaters to participate in the study. Ice availability to measure on-ice jump performance was limited to specific days and times that were available after figure skating or hockey practices were fulfilled, which limited the number of participants who had this specific time frame open. Due to the nature of figure skating blades and the ice that figure skaters perform on, on-ice jump peak power was calculated via a theoretical approximation instead of using a force plate.

**Assumptions**
An assumption was made that the researcher gathered reliable and valid measures when conducting on and off-ice testing. Maximal effort was assumed from all participants throughout all testing measures. When reporting information regarding injuries within the past 30 days, honesty on the interest survey that all figure skaters have to fill out prior to participating in the study was assumed from all participants.

**Key Definitions**

- *Figure skater* is a term used to speak of male and female figure skaters, throughout this manuscript.
- *Jump performance* refers to a figure skater’s vertical and horizontal jump distances, vertical jump speed, translational power, and jump flight-time.
- *Toe-pick* refers to the front most part of a figure skater’s blade. The blade is located under the leather boot that skaters wear snugly on their feet.
- *Flight-time* is the amount of time that a figure skater has both limbs off of the ground. The time begins when the toe-pick of the take-off leg leaves the ground and ends when the toe-pick of the landing leg makes contact with the ice.
- *Figure skaters* and participants was used interchangeably throughout this study.
- *Single axel jump* is a one and a half revolution (540 degrees) jump in which figure skaters take-off from a single-leg forward outside edge and then land on the single-leg backward outside edge of the opposite foot.
- *Skating edge* is the direction that a figure skating blade is tilted in regards to their weight distribution.
• **Propulsion phase** begins when the figure skater places their toe-pick into the ice and ends when their toe-pick leaves the ice.⁴

• **Stroking** is a figure skating move which involves backward or forward skating propelled by pushing from the edge of one figure skating blade and then gliding on the opposite foot that performed the push.

• **Stepping out** is a term that is commonly used in figure skating to represent when a figure skater does not land a jump properly. When a jump is not executed properly, there is a tendency for figure skaters to land and then continue to turn and need to step on their non-landing foot instead of holding the landing edge.

• **Synchronized figure skaters** are defined as a group of 12-24 figure skaters who perform a synchronized figure skating routine.
CHAPTER 2

LITERATURE REVIEW

Figure Skating

Premiering in the 1908 Olympic Games, figure skating is one of the oldest sports still present in today’s Olympic Games. The men’s and lady’s single events are popular amongst figure skating communities worldwide; however, dance, pairs, and synchronized events have gained more popularity over the last decade, but have yet to surpass the singles events. As figure skating has evolved, competitive focus has shifted from control and flow to difficulty and precision. This transition is evident in the men and ladies single events, where competitive success has become more dependent on the increasing difficulty of jumps. With an added focus on technical difficulty, coaches and figure skaters allocate a large proportion of practice time to perfecting jump technique and increasing jump flight-times.

Jump performance has typically been trained using on-ice jump drills, where figure skaters attempt un-mastered jumps which often result in falls, potentially increasing risk of injury. Alternatively, some figure skaters utilize off-ice jumping training, which may decrease the chance for injuries caused by repeated falling on ice due to un-mastered jumps. This type of training often includes jump technique and rotational exercises, and is typically performed on a “softer” surface, compared to the ice, while wearing exercise shoes. Off-ice strength and power training may help to increase lower body strength and power measure in figures skaters which may translate to an increase in
on-ice jump performance; however, very few researchers have investigated this possibility.

During their prepubescent years, female figure skaters typically focus on multiple revolution jump advancements, as this is the typical age of sport specility. In a cross-sectional retrospective study, female pre-elite and elite figure skaters were found to reach menarche at an average age of 13.8 years. During puberty, females will typically increase body fat mass, which may result in a change in the orientation of their center of mass (COM). This change may decrease jump height and shorten rotational speed in female figure skaters. As a female progresses through puberty, an increase in body transverse diameters may make jump revolutions more difficult to learn than to maintain, which may increase the pressure for female figure skaters to master triple revolution jumps well before 13 years of age.

Men’s figure skating focuses heavily on quadruple revolution jump landings, and thus it is the ultimate goal of many male figure skaters to master a quadruple revolution jump. A study of 233 junior elite male figure skaters, reported that males start figure skating between the ages of three and 11 years of age. Male figure skaters typically do not specialize until after the age of eight years old. With the sport specialization for male skaters typically occurring a couple of years after females, a greater emphasis is placed on males to master technical jumps in a shorter period of time.

**Demands of the sport.** Repetitive jumps play a large role in a figure skater’s practice routine. As a skater progresses throughout their career, they will typically train between four and six hours a day, five to six days per week, and 50 weeks per year. The time spent on-ice may be between two to four hours each day, and may include more
than 30 minutes solely focused on jump techniques and landings. Based on research by Bruening and Richards, figure skaters frequently performed up to 50-100 on-ice jumps each day that they practiced.

The high level of ground reaction forces (GRF) that a figure skater withstands with each jump landing, places a large stress on their lower extremities. Boldt found the vertical GRF that a figure skater withstands, during a jump landing, to be six and a half times a figure skater’s body weight. Bruening and Richard found similar results, when they further broke down GRF into peak toe and heel forces. They found peak toe force to be just over two and a half times greater than a figure skaters body weight and heel force to be five times greater than their body weight. Wearing figure skates adds extra weight and produces a plantar flexion limitation of the ankle, which increases the GRF of on-ice jumps by increasing the total weight and decreasing the ability to absorb jump landings. Bruening and Richard studied the effect of articulated figure skating boots that allowed for a fuller range of motion in the sagittal plane and yet stability in the frontal plane. They found this figure skate design to decrease jump landing GRF; however, figure skaters indicated that the articulated skates were difficult to skate in.

Injuries. Prepubescent figure skaters who are learning to perform double, triple, and quadruple revolution jumps may be at increased risk of sustaining injury. Smith, et al suggests that the stress of on-ice training may not be sustained by a youth figure skater’s musculoskeletal system. As youth figure skaters attempt to master new on-ice jumps, they may place excessive force on the soft tissues of the foot and ankle. Jumps that are performed with poor technique or do not have enough flight-time and angular momentum to successfully complete the jump in may result in musculoskeletal trauma.
Figure skaters skating in the singles event may undergo many acute or chronic injuries throughout their careers. Within figure skating, approximately 50 percent of injuries result from acute injuries, while the other 50 percent are the result of chronic injuries.\textsuperscript{22} The predominate sites for injuries suffered by figure skaters are the ankles, knees, or hips.\textsuperscript{11}

Chronic injuries that figure skaters typically suffer from consist of tendonitis, pain, swelling, stress fractures, and ankle spurs.\textsuperscript{22} Acute injuries may include muscle strains, fractures, concussions, lacerations, sprains, and tears to ligaments. In a one-year study of eight elite figure skaters, 56\% of injuries were acute and 44\% were chronic. Dubravic-Simunjak, et al\textsuperscript{18} demonstrated in their study that 79.5\% of over 400 elite junior figure skaters sustained at least one major figure skating-contributed injury throughout their careers.

Figure skaters in the singles events have a greater percentage of overuse injuries than any other figure skating style.\textsuperscript{18} Most overuse injuries are found in figure skaters’ lower extremities.\textsuperscript{10,18,23,24} Fortin and Roberts\textsuperscript{25} evaluation of 208 national figure skaters found the distribution of acute and chronic injuries to be 28\% ankle, 19\% knee, 15\% back, and the remaining 38\% to be located in other areas of the body. Stress fractures are a specific concern as they may often be the result of the high stresses and minimal rest periods which are common to figure skaters, and can present in the fibula, tibia, navicular, and metatarsal bones.\textsuperscript{26,27} Lower extremity injuries caused by improper jump landings due to overuse or fatigue may reduce a figure skaters’ ability to practice at high intensities, and may play a role in reducing the longevity of their careers. Kjaer, et al\textsuperscript{23} found that the rate of injury that prevented figure skaters from participating in on-ice
activities, was approximately one and a half injuries per 1,000 hours of on-ice training. This equates to figure skaters sustaining at least one injury per year.

**Jump requirements.** There are six different jump categories that figure skaters performed during their routines. The jumps vary in difficulty level and the number of revolutions that can be performed. The 2015 Official U.S. Figure Skating Rulebook rates the different jump categories in the following order of difficulty: toe loop, salchow, loop, flip, lutz, and axel. Figure skaters master single, double, triple, and then quadruple revolution jumps. The axel is the only jump that takes off from a forward position and has the highest level of difficulty associated with it. The triple axel (three and a half rotations) is one of the most difficult jumps that female figure skaters attempt in competition. The quadruple revolution jump is a non-expressed expectation in men’s figure skating, and is becoming common expectation in their skating routines.

**Program jump components.** Singles figure skaters have a minimum requirement of attempting three jumps during their short program, while there is a maximum of eight jump attempts for men and seven jump attempts for ladies, during the long program. In the long program, three of the seven or eight jump attempts must be performed in combination. The combination jump element is composed of two-three jumps, performed in a series one after the other. The combination jump component has figure skaters performing up to 12 jumps during a 4-4:30 minute long program. There are specific requirements for the types of jumps and combinations that can be executed; however, a specific number of revolutions is not required. Base jump value points are determined by the level of difficulty and the type of jump performed, leading to an overall score, which is adjusted for quality of execution.
attempted increases the base score of each jump leading skaters to perform jumps with triple and quadruple revolutions. Points are deducted if figure skaters do not fully rotate their jumps or fall while landing.\textsuperscript{1}

**Jump Performance Variables**

There are many variables involved in successful figure skating jumps, however, the most common is a fully rotated jump that lands on a single foot.\textsuperscript{28} Figure skaters who achieve these two requirements may receive close to the maximal points that are possible for the specific jump category that they are performing. Biomechanical research suggests that horizontal jump approach speed, vertical take-off velocity, flight-time, average angular velocity, jump endurance, and jump height are all important for successful figure skating jumps.\textsuperscript{3,4,29,30}

**Horizontal approach speed.** On-ice jump horizontal approach take-off speed is a variable that many coaches determine as a key element in successful jump performance.\textsuperscript{4} King et al\textsuperscript{4} studied the characteristics of triple and quadruple on-ice jumps at the 2010 Olympic games and concluded that a figure skater’s horizontal approach speed did not significantly differ whether attempting to perform a triple or quadruple revolution jump.

**Vertical take-off velocity.** Vertical velocity is primarily generated through the jump take-off leg triple extension (powerfully extending the hip, knee, and ankle) that launches the figure skater into the air during the propulsion phase.\textsuperscript{3} An eccentric muscle contraction occurs before the propulsion phase, suggesting initiation of the strength shortening cycle, which may help produce vertical velocity.\textsuperscript{4} An increase in vertical velocity may equate to an increase in jump height and thus, the overall time that a figure
skater has to perform revolutions in the air. \textsuperscript{4} Research indicates that vertical take-off velocity is similar for high to low revolution jumps, when figure skaters are at an elite level. \textsuperscript{2,3,31} For example, a study by King et al\textsuperscript{4} demonstrated that figure skaters who were able to perform a triple axel jump had a faster vertical take-off velocity on a double axel jump than those who could not land a triple axel jump.

\textit{Jump flight-time and average angular velocity.} The time that a figure skater spends in the air while jumping (jump flight-time) and the rate of change in angular position of their rotating body (average angular velocity) are important to jump performance for figure skaters. \textsuperscript{30} A figure skater who increases their jump height and achieves a quick rotational position may complete greater rotational time in the air, which may then result in more jump revolutions. \textsuperscript{4,6,9} When comparing double and triple jumps, Aleshinsky\textsuperscript{30} found that figure skaters tended to have the same timing pattern for the period that they spend in the air on each specific jump category, regardless if double or triple revolutions were performed. In contrast to this finding, Albert and Miller\textsuperscript{31} reported longer flight-times when comparing the double axel jump to single axel jump, suggesting that jump flight time increases parallel to the number of completed jump revolutions. Additionally, they advocate figure skaters reaching an individual “flight time” for all jumps performed, independent of the number of repetitions. They also suggest that at the point in which this individual “flight-time” is reached, angular momentum (moment of inertia x angular velocity) should become the primary focus to increase jump performance along with producing greater vertical force upon take-off.\textsuperscript{4}

\textit{Jump endurance.} Jump endurance can be defined as a figure skater’s ability to perform multiple jumps over the course of a practice session or competition\textsuperscript{29} and may be
a key component in successful jump landings. Polishchuk et al\textsuperscript{29} concluded that figure skaters between the ages of 6-18 had proficient jump endurance during a jump test consisting of 10 jumps with 10 seconds of rest between each jump. Additionally, the 8-12 age group experienced a decrease in maximal on-ice jump push-off strength, as compared to the 13-16 age group suggesting that figure skaters gain strength as they develop. Therefore, figure skating coaches may need to spend more time focusing on improving the strength and power of take-offs in young prepubescent figure skaters.\textsuperscript{29}

\textbf{Jump height.} On-ice jump height is generated by a figure skater’s toe-pick being placed into the ice, to push off and launch their bodies into the air.\textsuperscript{3} On-ice jump heights are determined by the change in displacement of a figure skaters center of mass and have been compared to jump flight-times of varying revolution jumps.\textsuperscript{2,4,30} A study by King et al\textsuperscript{2} showed that figure skaters tended to jump the same height when performing single, double, and triple axels. King\textsuperscript{4} also reported in another study that figure skaters proficient at quadruple toe-loops had increased jump height and flight-time, when compared to those figure skaters who could not yet perform a quadruple jump. Aleshinsky\textsuperscript{30} concluded that high level figure skaters had increased jump heights, as well as increased takeoff velocities, compared to those of lesser levels.

\textbf{Off-ice Strength and Power}

Off-ice resistance training and conditioning sessions have become more prevalent over the last decade,\textsuperscript{7} however, these sessions include minimal time and intensities, and can also be inconsistent.\textsuperscript{6} Off-ice strength training is typically performed by high or elite level figure skaters, although to our knowledge, there is limited research linking off-ice training to on-ice performance. Poe\textsuperscript{7} suggests that strength and power training should be
implemented into a figure skaters weekly training regimen, which may theoretically help a skater achieve their maximal jump potential. Hunnicut et al\textsuperscript{8} studied the effect of a low to moderate plyometric training program and found increased on-ice flight-times, off-ice vertical jump heights, and off-ice standing long jumps in synchronized figure skaters. Some examples of off-ice training include jumping drills, squats, deadlifts, plyometrics, and other exercises that would improve upper and lower body strength and power.

Off-ice training may translate to helping improve on-ice jump performance.\textsuperscript{6,7,9,12,13} King et al\textsuperscript{3} concluded that improved strength of the upper and lower body may play a role in figure skater’s ability to generate vertical velocity, which is an essential factor in improving on-ice jump flight-time. Jump flight-time has been shown to play a large role in figure skaters ability to complete complex jumps such as jump with triple and quadruple revolutions. Lower body strength has been shown to correlate to vertical jump height both on an off-ice. Fatouros et al\textsuperscript{32} found that improved lower body strength and power increased off-ice vertical jump height.\textsuperscript{32} To date, there has only been one study that investigated the relationship of off-ice strength training and on-ice jump performance.\textsuperscript{9} Podolsky, et al\textsuperscript{9} found a “very strong” (r=0.8-1.0) statistically significant positive correlation between upper (r=0.88, p=0.02) and lower body (r=0.93, p=<0.01) strength measurements and on-ice jump height. Results indicated that muscle mass of the shoulders, knees, and hips were significantly correlated to the height of the on-ice single axel jump. Bower et al\textsuperscript{13} examined the relationship of off-ice speed, acceleration, vertical jump height, and slide board counts to that of on-ice speed and acceleration. In their study of synchronized figure skaters, off-ice measures of the slide board and vertical
jump height had statistically significant correlations to figure skater’s on-ice speed ($r= -0.732$, $p<0.01$; $r=0.69$, $p<0.01$) and acceleration ($r=0.69$, $p<0.01$; $r=-0.63$, $p<0.01$).

With the added focus of attaining difficult high revolution jumps before puberty, off-ice training measures that enhance strength and power need to be considered to advance a young skater’s jump performance and mitigate injury. Neuromuscular development via the stretch shortening cycle may be an adaptation that youth figure skaters can achieve and thus, increase their vertical jump heights which may allow for more time to complete jump revolutions on-ice.

**Summary**

Research has indicated that early specialization is common for female figure skaters and that it may be a requirement to reach the expert level of performance in figure skating. Females figure skaters typically peak in performance in their late teens to early 20s; whereas, males typically peak in their early to mid-20s. Injury mitigation and enhanced performance are key elements for figure skaters to be successful at an elite competitive level. The struggle to maintain or gain performance levels and mitigate jury may be directly affected by the amount of time figure skaters spend off-ice training.

Due to limited research, the relationship and predictability of off-ice strength and power measurements and on-ice jump performance should be assessed in figure skaters. It is important to access this relationship, as off-ice testing may be a way that strength and conditioning coaches can determine if their training programs are meeting the needs of figure skaters. Additionally, off-ice training may be a key component in extending the overall longevity of a figure skater’s career.
CHAPTER 3

METHODOLOGY

Introduction

Jump performance is crucial to the sport of figure skating, in both the technical merit and aesthetic components that are judged in competition.\(^{34}\) Off-ice training has been suggested as a means of enhancing on-ice jump performance.\(^{6-8}\) Previous research on the relationship between off-ice strength and on-ice jump performance, is limited to a study by Podolsky et al,\(^9\) which indicates a positive correlation between off-ice dynamic strength measures and on-ice jump heights. This finding provides useful information, but only considers one part of the strength power relationship as it relates to jump performance. Limited research on off-ice power measurements and on-ice jump performance indicates that a six week off-ice plyometric training routine significantly increased off-ice vertical and horizontal displacements, on-ice jump flight-time, and subjective jump self-evaluations in a collegiate synchronized figure skating team.\(^8\) The primary objective of this study was to investigate off-ice strength and power measures in competitive pre-elite to elite figure skaters and the predictability that off-ice strength and power variables may have to on-ice jump performance.

Research Design

A cross-sectional quasi-experimental design was used to examine off-ice strength and power measures in competitive pre-elite to elite figure skaters and the predictability of these variables to on-ice jump performance, over a two-week time period. Each figure skater performed an off-ice and on-ice testing session within this timeframe, with at least
24 hours between testing sessions. Each session began with a standardized warm up, followed by a submaximal familiarization phase, and lastly the on-ice or off-ice testing session.

Participants

Approval to conduct this study was provided by the University of Colorado Colorado Springs Institutional Review Board (Appendix J), prior to conducting this study. Coaches of the 7K International Figure Skating Club were contacted for their approval to recruit eight figure skaters from Monument, Colorado and the surrounding areas, who all had passed the United States Figure Skating Association (USFSA) Juvenile Freestyle test. Figure skaters at this level are able to complete a single axel jump, which requires a single foot take-off from a forward outside edge. This jump is easier to measure than the five other individual jump categories performed in figure skating and is also the most frequent jump used in research. 2,5,9,31

All participants underwent off-ice and on-ice testing performance measures conducted at the Sports Performance Center Skating Rink and 365 Performance, located in Monument, Colorado. Permission to utilize these facilities was obtained from the owner of the Sports Performance Center Skating Rink and 365 Performance and a signed letter of access was sent to the Institutional Review Board (IRB). The primary researcher conducted a recruitment meeting to answer any questions regarding participation in the study. To be included in the study, participants meet the following delimitation criteria: 1) Current figure skater between the ages of 8-22 years of age; 2) Competitive figure skater for at least one year; 3) Currently training on-ice at least six hours per/week; 4) Passed the United States Figure Skating Association (USFSA) Juvenile Freestyle test; 5)
One year of experience landing the axel jump; and 6) No injuries requiring a time loss training of three or more days in the past seven days.

Participants were informed that their participation was voluntary. The decision to participate did not impact any aspect of their respective club participation. For participants 11-16 years of age, an informed consent was sought from their parents or legal guardians, and then assent was sought from the minor athlete. Parents or legal guardians received a copy of both forms. Participant identities and data from the study were protected through the use of identification numbers. Data remained deidentified throughout the entire process; forms were stored in a locked cabinet in the factuly advisors office; and will be destroyed after three years utilizing the University’s contracted document shredding service.

**Off-ice Measurements**

Participants completed a demographics and exclusion criteria questionnaire which included questions related to: demographics, figure skating history, and off-ice training activities (Appendix F). Anthropometric measurements were collected at the beginning of the off-ice testing session. Height (cm) was measured using an open reel measuring tape (Champion sports, Marlboro, New Jersey). Body fat percentages were assessed with a bioelectrical impedance analyzer scale (Tanita TBF-521 Scale, Tanita Corporation; Japan). Participants and their figure skates were weighed on an Accupower force plate (AMTI Force and Motion, Watertown, MA), to determine their mass (kg) and the mass of their figure skates.
Upon completion of anthropometric measures, individual participants were instructed to perform a standardized five-minute warm-up. The warm-up was proctored by the primary investigator to ensure consistency and included 10 meters of dynamic light aerobic jogging variations (two minutes) and dynamic stretching (three minutes). The dynamic light aerobic jogging movements included: forward jogging, backward jogging, forward high knees, backward high knees, forward high heels, backward high heels, and lateral shuffle with the right and then left foot leading. Dynamic stretching included: walking knee hug, walking quad pulls, walking leg cradles, walking hamstring stretches (goose walk), lateral side to side lunge, and T-balance steps (one leg lifted to the back).

Upper and lower body strength and power measurements were collected, during one off-ice testing session. The off-ice testing session was followed by at least 24 hours of rest before completing the on-ice testing session. A familiarization period was allowed at the beginning of each individual testing variable, which included verbal explanation and a physical trial of up to 50% of maximal effort of each off-ice testing measure. The S.T.A.R.S. tuck jump was the only exception, where participants were allowed to perform up to five continuous tuck jumps. Each participant’s lower body strength and power were measured via a vertical jump and standing long jump (broad jump). To assess upper body strength and power, a reverse overhead medicine ball toss for distance was utilized. Lower body strength-endurance was measured with the use of a timed 30-second S.T.A.R.S. tuck jump assessment.

**Independent Variables**
**Off-ice vertical jump height variables.** Lower body power was assessed through the analysis of vertical jumps. A countermovement jump (CMJ), was used to assess lower body strength and power, because of its similar mechanisms to on-ice figure skating. Jump height, flight time, peak vertical velocity, GRF, and peak power were all measured via an Accupower force plate (AMTI Force and Motion, Watertown, MA). All jump attempts were simultaneously captured, using Kodak Playsport video cameras (©Kodak 2009, model Zx3; Rochester, NY) with a 60hz frame speed, in the sagittal plane of movement. Dartfish® software (Dartfish®, Version 8.0; Alpharetta, GA) was also utilized to analyze vertical jump height and flight time. The percent difference between the force plate and Dartfish® software (Dartfish®, Version 8.0; Alpharetta, GA) vertical jump height and flight time was calculated to determine the variability that may be present when using Dartfish® software (Dartfish®, Version 8.0; Alpharetta, GA) to analyze on-ice jump performance. The Sayers equation (PAPw (Watts) = 60.7 x jump height (cm) + 45.3 x body mass (kg) – 2055) was utilized to predict the vertical jump height from the force output of the force plate, which has been shown to be a valid measure of peak power (r=0.967).35

To begin the CMJ test via the Accupower force plate (AMTI Force and Motion, Watertown, MA) and Dartfish® (Dartfish®, Version 8.0; Alpharetta, GA), participants stood with legs extended and feet shoulder to hip width apart in the center of the force plate. When given the command “go,” participants performed the counter movement portion of the jump, by squatting to a position where their knees reach approximately 90 degrees of flexion. From this position, participants maximally pushed off of the force plate in a vertical direction, with both feet to achieve an extended leg position.
Participants were instructed to maintain this extended leg position for the duration of each jump, because tucking of the legs may artificially increase flight-time. Attempts with bent legs, during jump flight-time, were not counted to avoid confounding the results. Each participant was allowed three jump trials at 50% of their maximal efforts with 30 seconds of rest between jumps. Average vertical peak power, peak velocity, flight-time, and GRF were calculated and analyzed via Accupower force plate software (AMTI Force and Motion, Watertown, MA). Flight-time and vertical jump height were also calculated and analyzed using Dartfish® software (Dartfish®, Version 8.0; Alpharetta, GA). A set reference piece of athletic tape was placed on the force plate to the outside of the athlete’s feet to aid in the Dartfish® analysis.

**Off-ice standing long jump.** The National Strength and Conditioning Association’s standing long jump test protocol was utilized to measure participant’s off-ice horizontal jump distance. The standing long jump has been showed to be a valid method of measuring lower body strength. Participants began this assessment with the toes of their shoes behind a piece of tape allotted as the starting line. A countermovement long jump was performed, with participants jumping in a maximal forward movement. An attempt was not counted if, after landing, the participants move their feet or touched the ground with their hands before holding the landing position for five seconds. The distance of the jump was measured from the starting line where the toes were lined up to the participant’s posterior calcaneus. Each participant was allowed three jump trials at 50% of less of their maximal intensities, with 30 seconds of rest between trials, and the average of these measurements rounded to the nearest half centimeter were used for analysis.
**Off-ice reverse overhead medicine ball toss.** Upper body power has been shown to be a valid way off assessing upper body strength and was assessed using a reverse overhead medicine ball toss. Participants began by standing backwards at an allocated start line. A six-pound medicine ball was held with both hands. Participants then maximally tossed the ball over their heads in a backwards direction from the front of the body with an approximate 45-degree angle, while not favoring one arm over the other or rotating from the spine. The participant remained in contact with the ground with both feet in order for a trial to be counted. There were three trials allowed at 50% of less of their maximal intensities with 30 seconds of rest between and the longest distance was used for analysis.

**Off-ice 30-second tuck ump.** To assess jump endurance, participants performed the United States Figure Skating Association (USFSA) S.T.A.R.S. (Standardized Testing of Athleticism to Recognize Skaters) timed tuck jump assessment test. A reference height was marked via an exercise band where participant’s knees were bent at a 90-degree angle when in the air while performing a familiarization tuck jump. Participants began the test by performing tuck jumps that were at or above band marked height. Maximal number of jumps that met the marked height, within the allotted 30-second time frame, were counted and used for analysis.

**On-ice Measurements**

On-ice testing sessions were performed at least 24 hours after off-ice measurements were taken. A jump familiarization period was allowed, during the participant’s warm-up. This included a verbal explanation of the procedures and location that the jump test measures were to be taken. On-ice jump performance was analyzed by
evaluating vertical jump height, peak power, and jump flight-time. Each participant was given five minutes of on-ice warm-up time, which consisted of stroking and no more than five single jump familiarizations.

All jump attempts were captured, using a Kodak Playsport video camera (©Kodak 2009, model Zx3; Rochester, NY) with a 60hz frame speed, in the sagittal plane of movement. Imagery collected was analyzed using Dartfish® software (Dartfish®, Version 8.0; Alpharetta, GA). A known reference distance was placed within the camera’s plane of view. The camera was placed in a position where it could capture the participant’s full body image while they were executing jump attempts.

Light emitting diode (LED) lights (University of Colorado Colorado Springs Space Grant Lab; Colorado Springs, CO) was utilized as a way of tracking the height of each jump. Figure skaters wore small homemade elastic bands, which covered the bone landmarks of the ankle, knee, hip, and shoulder (Figure 1.). The small LED lights were attached on to the elastic bands and placed over the participant’s left and right side lateral malleolus, lateral condyles of the femur, top of the iliac crest, and the acromion processes.

**Figure 1.** LED placement.
**On-ice jumps.** Participants performed single axel jumps from their most comfortable approach, either from a single right or left foot take-off. The axel jump takes-off from a forward single-leg, inside edge, and consists of one and a half revolutions (540 degrees for the single), landing backwards on the opposite single-leg outside edge.28

**Jumping procedures.** Figure skaters were instructed to perform three maximal jump height attempts, within a 15 feet measured out area marked where specific lines were already painted on the ice, this emphasized where to begin and complete the jump. Participants were allowed 30-seconds of rest between jump attempts and utilized a self-selected approach to build speed for jump take-offs, as long as they completed the jump take-off within the allocated take-off area. Failed jump attempts included falling, landing on two feet, putting hand/hands on ice, and stepping out, and were not counted and another attempt was allowed for up to a maximum of 10 jumps.

**Dependent Variables**

**Power measurements.** On-ice peak power generated was measured indirectly via the Sayers equation (PAPw (Watts) = 60.7 x jump height (cm) + 45.3 x body mass (kg) – 2055). This equation was utilized to estimate participant’s peak power output for each of their jumps. Canavan and Vescovi35 found this equation to be an accurate measure of peak power. The weight of each participant included the weight of their figure skates. Jump height was collected with the Kodak Playsport video camera (©Kodak 2009, model Zx3; Rochester, NY) speed of 60 frames/min and analyzed via Dartfish® software (Dartfish®, version 8.0; Alpharetta, GA) and was corrected via the percent difference value that was determined off-ice. This percent difference was calculated using the
following equation: 100 x ([predicted (dartfish) – actual (force plate)]/actual (force plate)). The average peak power of all three jump attempts was used for analysis.

*Jump flight-time.* Flight-time was analyzed via the captured videos using a Kodak Playsport video camera (©Kodak 2009, model Zx3; Rochester, NY). Dartfish® software (Dartfish®, version 8.0; Alpharetta, GA) was utilized to determine on-ice jump flight-time. All resulting times were adjusted to reflect percent difference determined in the off-ice Dartfish® to force plate comparison.

*Vertical jump height.* Dartfish® software (Dartfish®, version 8.0; Alpharetta, GA) was used to analyze videos captured using a Kodak Playsport video camera (©Kodak 2009, model Zx3; Rochester, NY) for on-ice vertical jump height measurements. All measurements were adjusted to reflect percent difference determined in the off-ice Dartfish to force plate comparison.

**Data Collection**

Data collection began at the Sports Performance Center and 365 Performance February in 2016 and concluded March 2016. Off-ice and on-ice measures were taken over the course of a two-week period. The primary researcher performed all testing sessions and measurements.

**Statistical Analysis**

Statistical analyses was conducted using IBM® SPSS® (Version 23.0) software. Analysis was based on linear regression and correlations. Pearson correlations were utilized to examine bivariate relationships between the off-ice and on-ice testing measures. Multiple regression analyses were utilized to determine how off-ice testing
measures related to on-ice testing measures and also were used to ascertain differences by rank. Austin and Steyerberg\(^{40}\) concluded that two participants were required per variable to achieve a relative bias of less than 10\% in estimate of regression coefficients. Due to having eight participants and eight variables, two regression equations were utilized. One-way analysis of variance was performed to compare figure skater’s freestyle level and all off-ice and on-ice testing measures. A significance level was set at \(p \leq 0.05\) and all results were reported as means and standard deviations. Strength of correlations were reported using the five groups of strength values by Evans\(^{41}\) that are based on the absolute value of the correlation coefficient (\(r\)): very weak (\(r = 0.00–0.19\)), weak (\(r = 0.20–0.39\)), moderate (\(r = 0.40–0.59\)), strong (\(r = 0.60–0.79\)) and very strong (\(r = 0.80–1.00\)). The results of this study presented what off-ice strength and power measures were of the greatest predictors of on-ice jump performance.
CHAPTER 4
MANUSCRIPT

Introduction

The sport of figure skating has evolved over time, with competitive focus shifting from control and flow to difficulty and precision.\(^1\) In the men’s and lady’s single events, competitive success has become more dependent on the increasing difficulty of jumps.\(^1-3\) With an added focus on technical difficulty, coaches and figure skaters allocate a large proportion of practice time to perfecting jump technique and increasing jump flight-times.\(^4\)

Repetitive jumps play a large role in a figure skater’s practice routine. In a study performed by Bruening and Richards,\(^5\) figure skaters were found to perform up to 50-100 on-ice jumps each day that they practiced. Both on-ice and off-ice jump training procedures may currently be used to increase jump performance among figure skaters. Figure skaters typically train on-ice using jump drills and by attempting to perform un-mastered jumps, often resulting in falls.\(^6\) Alternatively, some figure skaters utilize off-ice jump training, which may decrease the chance for injuries caused by repeated falling on ice due to un-mastered jumps.\(^6\) Off-ice strength and power training may help to increase lower body strength and power measures in figures skaters,\(^7\) which could translate to an increase in on-ice jump performance. The struggle to maintain or gain performance levels and mitigate injury may be directly affected by the amount of time a figure skaters spends in off-ice training.\(^7-11\) Therefore, off-ice training may be a key component in extending the overall longevity of a figure skater’s career.
Off-ice strength and power training has been suggested as a way to improve figure skaters jump performance.\textsuperscript{6,7,9,12} This method of training may help increase the explosiveness of jump takeoffs by improving lower body strength, and may also give figure skaters the ability to complete more technical jumps, such as those with triple and quadruple revolutions.\textsuperscript{2,9} On-ice jump height has been shown to correlate with upper and lower body strength measures amongst figure skaters.\textsuperscript{7} To date, the relationship of power measures and jump performance has only once been researched in teams of synchronized figure skaters.\textsuperscript{8}

The predictability of collective strength and power measurements and jump performance has yet to be studied. To date, there have been limited studies investigating the relationship of off-ice measures to on-ice performance. Podolsky, et al\textsuperscript{9} found a “very strong” ($r=0.8-1.0$) statistically significant positive correlation between upper ($r=0.88$, $p=0.02$) and lower body ($r=0.93$, $p=<0.01$) strength measurements and on-ice jump height. Results indicated that muscle mass of shoulders, knees, and hips were significantly correlated to the height of the on-ice single axel jump. In a study of synchronized figure skaters, off-ice measures of the slide board and vertical jump height had statistically significant correlations to figure skater’s on-ice speed ($r=-0.732$, $p<0.01$; $r=0.69$, $p<0.01$) and acceleration ($r=0.69$, $p<0.01$; $r=-0.63$, $p<0.01$).\textsuperscript{13} Additionally, Hunnicut et al\textsuperscript{8} studied the effect of a low to moderate plyometric training program and found increased on-ice flight-times, off-ice vertical jump heights, and off-ice standing long jumps in synchronized figure skaters. This limited research indicates that additional investigation is warranted to investigate the relationship and predictability of off-ice strength and power measurements to on-ice jump performance among figure skaters.
Methodology

A cross-sectional quasi-experimental design examined the off-ice strength and power measures of nine competitive pre-elite to elite female figure skaters (14.3±1.8 years; 158.5±5.0 cm; 48.9±7.16 kg) and the predictability of these variables to on-ice jump performance, over two different testing sessions. University Institutional Review Board approval was obtained and data collection was performed at an off campus skating performance center.

Figure skating club coaches were utilized to assist in participant recruitment. They were instructed that participants needed to meet the following delimitation criteria: 1) Current figure skater between the ages of 8-18 years of age; 2) Competitive figure skater for at least one year; 3) Currently training on-ice at least six hours per/week; 4) Passed the United States Figure Skating Association (USFSA) Juvenile Freestyle test; 5) One year of experience landing the axel jump; and 6) No injuries requiring a time loss training of three or more days in the past seven days.

All participants were informed that their participation was voluntary. Assent was obtained for participants 11-16 years of ages, in addition to informed consent from their parents or legal guardians. Participant identities and data from the study were protected through the use of identification numbers. Prior to data collection, participants completed a demographic and exclusion criteria questionnaire.

**Off-ice measurements.** Anthropometric measurements were collected at the beginning of the off-ice testing session. Height (cm) was measured using an open reel measuring tape (Champion sports, Marloro, New Jersey). Body fat percentages were assessed with a bioelectrical impedance analyzer scale (Tanita TBF-521 Scale, Tanita
Corporation; Japan). Participants and their figure skates were weighed on an Accupower force plate (AMTI Force and Motion, Watertown, MA), to determine their mass (kg) and the mass of their figure skates. Participants then performed a standardized five-minute warm-up, which included 10 meters of dynamic light aerobic jogging variations (two minutes) and dynamic stretching (three minutes). Upper and lower body strength and power measurements were collected via a reverse overhead medicine ball toss, timed 30-second S.T.A.R.S. tuck jump assessment, vertical CMJ, and standing long jump (broad jump). A familiarization period was allowed at the beginning of each assessment, which included a verbal explanation and a physical trial of up to 50% of maximal effort for each testing measure. The S.T.A.R.S tuck jump was the only exception, where participants were allowed to perform up to five continuous tuck jumps. The off-ice testing session was followed by at least 24 hours of rest and prior to on-ice testing.

A countermovement jump (CMJ), was used to assess lower body power, because of its similar mechanisms to on-ice figure skating. To begin the CMJ test, participants stood with feet between shoulder and hip width apart and legs extended in the center of the force plate. Participants performed the counter movement portion of the jump, by squatting to a position where their knees reached approximately 90 degrees of flexion and then maximally pushing off of the force plate in a vertical direction with both feet to achieve an extended leg position. Participants were instructed to maintain an extended leg position for the duration of jump flight-time and attempts with bent legs, during jump flight-time, were not counted. Each participant was allowed three jump trials with 30 seconds of rest between jumps. Jump height, flight time, peak vertical velocity, ground reaction force (GRF), and peak power were measured via the Accupower force plate
(AMTI Force and Motion, Watertown, MA). All jump attempts were simultaneously captured, using Kodak Playsport video cameras (©Kodak 2009, model Zx3; Rochester, NY) with 60hz frame speed, in the sagittal plane of movement. Dartfish® software (Dartfish®, Version 8.0; Alpharetta, GA) was utilized to analyze vertical jump height and flight time. A piece of athletic tape was placed on the force plate and used as a reference point in Dartfish®. The percent difference between the force plate (actual) and Dartfish® software (predicted) vertical jump height and flight time were calculated to determine the variability of using Dartfish® software to analyze on-ice jump performance as compared to a force plate. The Sayers equation \( PAPw (\text{Watts}) = 60.7 \times \text{jump height (cm)} + 45.3 \times \text{body mass (kg)} - 2055 \) was utilized to predict the vertical jump height from the force, which has been shown to be a valid measure of peak power \((r=0.967)\).^{35}

The National Strength and Conditioning Association’s standing long jump test protocol,\(^{36}\) which has been shown as a valid method of measuring lower body strength,\(^{37}\) was utilized to measure participant’s off-ice horizontal jump distance. A reverse overhead medicine ball toss was used to assess upper body power, because research has demonstrated that is a valid method of assessing upper body strength and power.\(^{38}\) Participants began by standing backwards at an allocated start line holding a six-pound medicine ball with both hands. Participants maximally tossed the ball over their heads in a backwards direction from the front of the body with an approximate 45-degree angle, ensuring not to favor one arm over the other or rotating from the spine, while maintaining contact with the ground with both feet. Three trials were allowed with 30 seconds of rest between them and the longest distance was recorded for analysis.
To assess jump endurance, participants performed the USFSA S.T.A.R.S timed tuck jump assessment test. A reference height was marked via an exercise band where participant’s knees were bent at a 90-degree angle when in the air while performing a familiarization tuck jump. Participants began the test by performing tuck jumps that were at or above band marked height. Maximal number of jumps that met the marked height, within the allotted 30-second time frame, were counted and used for analysis.

**On-ice measurements.** On-ice testing occurred at least 24 hours after off-ice assessments and included a jump familiarization period, during the participant’s five minute warm-up, which consisted of stroking and no more than five single axel jump familiarizations at 50% of the participant’s maximal effort. Participants were provided a verbal explanation of the procedures and location that the jump test measures were to be recorded. On-ice jump performance was then analyzed by evaluating vertical jump height, peak power, and jump flight-time.

All jump attempts were captured, using a Kodak Playsport video camera (©Kodak 2009, model Zx3; Rochester, NY) with 60hz frame speed, in the sagittal plane of movement. Imagery collected was analyzed using Dartfish® software (Dartfish®, Version 8.0; Alpharetta, GA). The camera was positioned to capture participant’s full body image while they executed jump attempts. A known reference distance was placed via a 6 inch piece of athletic tape horizontally coving the participant’s umbilicus and could be seen within the camera plane of view. Light emitting diode (LED) lights (University of Colorado Colorado Springs Space Grant Lab; Colorado Springs, CO) were utilized to track the height of each jump. Figure skaters wore small homemade elastic bands, which covered the bony landmarks of the ankle, knee, hip, and shoulder. The
small LED lights were attached to the elastic bands and placed over the participant’s lateral malleoli, lateral femoral condyle, iliac crest, and the acromia process.

Participants performed single axel jumps from their most comfortable approach, either from a single right or left foot take-off. The axel jump takes-off from a forward single-leg, inside edge, and consists of one and a half revolutions (540° for the single), landing backwards on the opposite single-leg outside edge.\textsuperscript{28} Figure skaters were instructed to preform three maximal jump height attempts, within a 15 feet measured area. Participants were allowed 30-seconds of rest between jump attempts and utilized a self-selected approach to build speed for jump take-offs, as long as they completed the jump take-off within the allocated take-off area. Failed jump attempts included falling, landing on two feet, putting hand/hands on ice, and stepping out were not counted and another attempt was allowed for up to a maximum of 10 jumps.

The Sayers equation (PAPw (Watts) = 60.7 x jump height (cm) + 45.3 x body mass (kg) – 2055) was utilized to predict the vertical jump height from the peak force gathered from the force plate. This equation has been shown to be a valid measure of peak power (r=0.967).\textsuperscript{35} The weight of each participant included their body mass and the weight of their figure skates. Averaged peak power of all three jump attempts was utilized for analysis, Jump height and flight-time was collected using Kodak Playsport video camera (©Kodak 2009, model Zx3; Rochester, NY) speed of 60 frames/min and analyzed via Dartfish\textsuperscript{®} software (Dartfish\textsuperscript{®}, version 8.0; Alpharetta, GA) and was corrected via the percent difference value that was determined off-ice. All measurements were adjusted to reflect percent difference determined in the off-ice Dartfish to force plate comparison.
**Statistical analysis.** Statistical analyses were conducted via IBM® SPSS® (Version 23.0) software. Analysis were based on linear regression and correlations. Pearson correlation was used to examine bivariate relationships between the off-ice and on-ice testing measures. Multiple regression analyses were utilized to determine how off-ice testing measures related to on-ice testing measures and also were used to ascertain differences by rank. Austin and Steyerberg\(^40\) concluded that two participants were required per variable to achieve a relative bias of less than 10% in the estimate of regression coefficients. Due to having eight participants and eight variables, two regression equations were utilized. One-way analysis of variance was performed to compare figure skater’s freestyle level and all off-ice and on-ice testing measures. Significance was set at \(p \leq 0.05\) and results were reported as means and standard deviations. Strength of correlations were reported using the five groups of strength values by Evans\(^41\) that are based on the absolute value of the correlation coefficient (r): very weak (\(r = 0.00–0.19\)), weak (\(r = 0.20–0.39\)), moderate (\(r = 0.40–0.59\)), strong (\(r = 0.60–0.79\)) and very strong (\(r = 0.80–1.00\)).

**Results**

**Participant’s descriptive statistics.** Descriptive statistics for the sampled figure skaters are presented as mean scores and standard deviations in Table 1. The sample consisted of nine female pre-elite to elite level figure skaters aged 14.3 \(\pm\) 1.8 years. Participant’s anthropometric variables can be found in Table 1. This sample of figure skaters spent on average 18.3 \(\pm\) 3.2 hours on-ice training each week, they averaged 3.9 \(\pm\) 1.6 hours of additional of sport specific training off-ice in a week, and completed an
average of $2.5 \pm 0.9$ hours of off-ice strength and conditioning each week. The age that participants began figure skating ranged from 3-11 years of age (Table 1).

**Table 1.** Descriptive Statistics for Figure Skaters (N=9)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>14.3 ± 1.8</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>158.5 ± 5.0</td>
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<tr>
<td>Body mass (kg)</td>
<td>48.9 ± 6.9</td>
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<tr>
<td>BMI (kg x m$^2$)</td>
<td>19.43 ± 2.013</td>
</tr>
<tr>
<td>Mass of skates (kg)</td>
<td>1.8 ± 0.3</td>
</tr>
<tr>
<td>Age began skating (years)</td>
<td>7 ± 2.7</td>
</tr>
<tr>
<td>On-ice skating (hours/week)</td>
<td>18.3 ± 3.2</td>
</tr>
<tr>
<td>Off-ice sport specific training (hours/week)</td>
<td>3.9 ± 1.5</td>
</tr>
<tr>
<td>Off-ice strength and conditioning (hours/week)</td>
<td>2.5 ± 0.9</td>
</tr>
</tbody>
</table>

**On-ice descriptive statistics.** Table 2 depicts the adjusted values for on-ice jump performance variables. After multiplying each variable by the percent difference found in Table 4 and subtracting that value from the initial variable (example: flight time of 0.425 sec. x 0.063 and subtracted from 0.425 sec. gives you 0.398 sec.), the adjusted values resulted in an on-ice average vertical jump height of $27.9 \pm 3.9$ cm and a vertical jump flight time of $0.398 \pm 0.03$ sec. Vertical jump peak power was calculated via the Sayers Equation$^{35}$ using the adjusted vertical jump height, and resulted in a mean power output of $2,011.2 \pm 394.1$ watts.

**Table 2.** Descriptive Statistics (Mean ± SD) for On-Ice Jump Performance (N=9)

<table>
<thead>
<tr>
<th>On-Ice Axel Jump Variables</th>
<th>Actual</th>
<th>Adjusted$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flight time (s)</td>
<td>0.425 ± 0.05</td>
<td>0.398 ± 0.03</td>
</tr>
<tr>
<td>Jump height (cm)</td>
<td>31.1 ± 5.5</td>
<td>27.9 ± 3.9</td>
</tr>
<tr>
<td>Peak power (watts)</td>
<td>2,205.7 ± 411.7</td>
<td>2,011.2 ± 394.1</td>
</tr>
</tbody>
</table>

$^a$ Adjusted values for Dartfish overestimate of 6.3% for flight time and 10.3% for jump height. Power was calculated via the use of the adjusted jump height.

**Off-ice descriptive statistics.** Off-ice independent variable descriptive statistics are presented in Table 3, where the variables are broken into two columns with one
containing off-ice non-vertical jump variables and the other with off-ice vertical jump variables.

**Table 3. Descriptive Statistics for Off-Ice Variables (N=9)**

<table>
<thead>
<tr>
<th>Off-ice Tests</th>
<th>Vertical Jump Variables</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overhead toss (cm)</td>
<td></td>
<td>552.9 ± 191.3</td>
</tr>
<tr>
<td>Long jump (cm)</td>
<td></td>
<td>198.8 ± 31.2</td>
</tr>
<tr>
<td>Stars tuck jumps in 30sec</td>
<td></td>
<td>46.4 ± 3.7</td>
</tr>
<tr>
<td>Sayers calculated jump height (cm)</td>
<td></td>
<td>36.5 ± 6.8</td>
</tr>
<tr>
<td>Dartfish jump height (cm)</td>
<td></td>
<td>40.2 ± 8.8</td>
</tr>
<tr>
<td>Force plate peak power (watts)</td>
<td></td>
<td>2,430.8 ± 764.9</td>
</tr>
<tr>
<td>Sayers peak power (watts)</td>
<td></td>
<td>2,728.7 ± 908.9</td>
</tr>
<tr>
<td>Force plate peak velocity (f/s)</td>
<td></td>
<td>7.9 ± 0.9</td>
</tr>
<tr>
<td>Force plate GRF (kg)</td>
<td></td>
<td>344.6 ± 92.0</td>
</tr>
<tr>
<td>Force plate flight-time (s)</td>
<td></td>
<td>0.48 ± 0.05</td>
</tr>
<tr>
<td>Dartfish flight-time (s)</td>
<td></td>
<td>0.51 ± 0.05</td>
</tr>
</tbody>
</table>

Dartfish and force plate comparison. Average off-ice vertical jump height and vertical jump flight-time are presented for both the Dartfish® (Dartfish®, version 8.0; Alpharetta, GA) and force plate (PASCO, model PS-2142; Roseville, CA), in Table 3. The values for these variables were found to be different (example: flight time Dartfish® = 0.53 ± 0.06 seconds and Force plate = 0.48 ± 0.04) and were further analyzed in Table 4. Pearson Correlation between vertical jump flight-time from the force plate and Dartfish® vertical jump flight-time showed significant very strong positive associations (r = 0.93, p ≤ 0.05) (Table 4). Although, this was not the same for vertical jump height from the force plate and vertical jump height using the Dartfish® method (r = -0.51, p ≤ 0.05), where a negative moderate correlation was found. Percent differences between the two collection methods were calculated for both vertical jump height and vertical jump flight time and resulted in Dartfish® over estimating vertical height by 10.3% and flight-time by 6.3%.
Characteristics of figure skaters. Statistically significant negative correlations were found between participants’ height descriptive statistics and the on-ice jump performance variables of off-ice vertical jump flight-time ($r = -0.629$, $p < 0.05$) and jump height ($r = -0.686$, $p < 0.05$) (Table 7). A moderate negative correlation was found between the ages that figure skaters stated skating and their on-ice jump flight-time. In addition, moderate negative correlations were revealed between figure skater’s body mass and their on-ice vertical jump flight-time and vertical jump height variables, along with figure skater’s height and on-ice vertical jump peak power (Table 5).

Table 4. Off-Ice Vertical Jump Variable Comparison (N=9)

<table>
<thead>
<tr>
<th>Off-ice tests</th>
<th>Dartfish</th>
<th>Force Plate</th>
<th>%Diff</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical jump height (cm)</td>
<td>40.2 ± 8.8</td>
<td>36.5 ± 6.8</td>
<td>10.3</td>
<td>-0.51</td>
</tr>
<tr>
<td>Flight time (cm)</td>
<td>0.51 ± 0.05</td>
<td>0.48 ± 0.05</td>
<td>6.3</td>
<td>0.93*</td>
</tr>
</tbody>
</table>

% Difference, 100 x ([predicted (dartfish) – actual (force plate)]/actual (force plate)); r, the correlation between force plate and dartfish predictions; *Statistical significance set at $p \leq 0.05$.

Off-ice and on-ice relationships. No significant positive correlations were found between off-ice performance test variables and on-ice jump performance variables (Table 6). Although, strong negative correlations showed some interactions between: on-ice vertical jump flight-time and off-ice flight time, long jump, and peak power; on-ice

Table 5. Pearson correlation coefficients of participant descriptive on-ice testing variables (N=9)

<table>
<thead>
<tr>
<th></th>
<th>Flight Timea</th>
<th>Vertical Jump Heighta</th>
<th>Peak Powera</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-0.353</td>
<td>-0.353</td>
<td>-0.087</td>
</tr>
<tr>
<td>Height</td>
<td>-0.629*</td>
<td>-0.686*</td>
<td>-0.492</td>
</tr>
<tr>
<td>Body mass</td>
<td>-0.479</td>
<td>-0.479</td>
<td>-0.167</td>
</tr>
<tr>
<td>Strength training time</td>
<td>-0.039</td>
<td>-0.275</td>
<td>-0.386</td>
</tr>
<tr>
<td>On-ice skating time</td>
<td>-0.063</td>
<td>0.063</td>
<td>0.093</td>
</tr>
<tr>
<td>Age began skating</td>
<td>-0.439</td>
<td>-0.126</td>
<td>-0.217</td>
</tr>
<tr>
<td>BMI</td>
<td>-0.171</td>
<td>-0.171</td>
<td>0.254</td>
</tr>
</tbody>
</table>

a = On-ice jump performance variables adjusted. * = Statistical significance set at $p \leq 0.05$. 

Characteristics of figure skaters. Statistically significant negative correlations were found between participants’ height descriptive statistics and the on-ice jump performance variables of off-ice vertical jump flight-time ($r = -0.629$, $p < 0.05$) and jump height ($r = -0.686$, $p < 0.05$) (Table 7). A moderate negative correlation was found between the ages that figure skaters stated skating and their on-ice jump flight-time. In addition, moderate negative correlations were revealed between figure skater’s body mass and their on-ice vertical jump flight-time and vertical jump height variables, along with figure skater’s height and on-ice vertical jump peak power (Table 5).

Table 4. Off-Ice Vertical Jump Variable Comparison (N=9)

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<tr>
<th>Off-ice tests</th>
<th>Dartfish</th>
<th>Force Plate</th>
<th>%Diff</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical jump height (cm)</td>
<td>40.2 ± 8.8</td>
<td>36.5 ± 6.8</td>
<td>10.3</td>
<td>-0.51</td>
</tr>
<tr>
<td>Flight time (cm)</td>
<td>0.51 ± 0.05</td>
<td>0.48 ± 0.05</td>
<td>6.3</td>
<td>0.93*</td>
</tr>
</tbody>
</table>

% Difference, 100 x ([predicted (dartfish) – actual (force plate)]/actual (force plate)); r, the correlation between force plate and dartfish predictions; *Statistical significance set at $p \leq 0.05$.

Characteristics of figure skaters. Statistically significant negative correlations were found between participants’ height descriptive statistics and the on-ice jump performance variables of off-ice vertical jump flight-time ($r = -0.629$, $p < 0.05$) and jump height ($r = -0.686$, $p < 0.05$) (Table 7). A moderate negative correlation was found between the ages that figure skaters stated skating and their on-ice jump flight-time. In addition, moderate negative correlations were revealed between figure skater’s body mass and their on-ice vertical jump flight-time and vertical jump height variables, along with figure skater’s height and on-ice vertical jump peak power (Table 5).

Table 5. Pearson correlation coefficients of participant descriptive on-ice testing variables (N=9)

<table>
<thead>
<tr>
<th></th>
<th>Flight Timea</th>
<th>Vertical Jump Heighta</th>
<th>Peak Powera</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-0.353</td>
<td>-0.353</td>
<td>-0.087</td>
</tr>
<tr>
<td>Height</td>
<td>-0.629*</td>
<td>-0.686*</td>
<td>-0.492</td>
</tr>
<tr>
<td>Body mass</td>
<td>-0.479</td>
<td>-0.479</td>
<td>-0.167</td>
</tr>
<tr>
<td>Strength training time</td>
<td>-0.039</td>
<td>-0.275</td>
<td>-0.386</td>
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</tr>
<tr>
<td>BMI</td>
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<td>-0.171</td>
<td>0.254</td>
</tr>
</tbody>
</table>

a = On-ice jump performance variables adjusted. * = Statistical significance set at $p \leq 0.05$. 

Off-ice and on-ice relationships. No significant positive correlations were found between off-ice performance test variables and on-ice jump performance variables (Table 6). Although, strong negative correlations showed some interactions between: on-ice vertical jump flight-time and off-ice flight time, long jump, and peak power; on-ice
vertical jump height and off-ice long jump and reverse overhead toss; and on-ice vertical jump peak power and off-ice vertical jump height, long jump, and vertical velocity (Table 6). Moderate positive correlations showed some interactions between: on-ice vertical jump flight-time and the off-ice S.T.A.R.S. tuck jumps (Table 6). Significant very strong and positive correlations were found between on-ice jump performance variables (Table 6). As on-ice vertical jump height and increased, vertical jump flight-time also significantly increased (p ≤ 0.05).

### Table 6. Pearson correlation coefficients of off-ice and on-ice testing variables (N=9)

<table>
<thead>
<tr>
<th></th>
<th>Flight time</th>
<th>Vertical jump height</th>
<th>Peak power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off-ice vertical jump height</td>
<td>-0.592</td>
<td>-0.408</td>
<td>-0.661</td>
</tr>
<tr>
<td>Off-ice flight-time</td>
<td>-0.657</td>
<td>-0.507</td>
<td>-0.556</td>
</tr>
<tr>
<td>Long jump</td>
<td>-0.748</td>
<td>-0.647</td>
<td>-0.651</td>
</tr>
<tr>
<td>S.T.A.R.S tuck jump</td>
<td>0.51</td>
<td>0.175</td>
<td>0.259</td>
</tr>
<tr>
<td>assessment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overhead toss</td>
<td>-0.535</td>
<td>-0.626</td>
<td>-0.358</td>
</tr>
<tr>
<td>Peak power</td>
<td>-0.639</td>
<td>-0.535</td>
<td>-0.544</td>
</tr>
<tr>
<td>Vertical velocity</td>
<td>-0.587</td>
<td>-0.519</td>
<td>-0.628</td>
</tr>
<tr>
<td>GRF</td>
<td>-0.711</td>
<td>-0.573</td>
<td>-0.471</td>
</tr>
<tr>
<td>On-ice flight time</td>
<td>-</td>
<td>0.810*</td>
<td>0.619</td>
</tr>
<tr>
<td>On-ice vertical jump height</td>
<td>0.810*</td>
<td>-</td>
<td>0.627</td>
</tr>
</tbody>
</table>

*a = On-ice jump performance variables adjusted; *= Statistical significance set at p ≤ 0.05.

**On-ice jump predictability.** After assessing multicollinearity of the independent variables, it was determined that off-ice flight-time and the S.T.A.R.S. tuck jump assessment where the only variables that could be further assessed. Multiple regression analysis revealed that off-ice flight-time was an overall better predictor of on-ice jump performance, when compared to the S.T.A.R.S. tuck jump assessment (Table 7). However, these predictors were not statistically significant (p ≥ 0.05). Of the total variance in on-ice vertical jump flight-time, off-ice flight-time and the S.T.A.R.S. tuck jump assessment accounted for 24.5% of the variance. For the total variance in on-ice
vertical jump height, off-ice flight-time and the S.T.A.R.S. tuck jump assessment accounted for 2%. In addition, off-ice flight-time and the S.T.A.R.S tuck jump assessment accounted for 11.7% of the variance in on-ice vertical jump peak power.

Table 7. Order of ranking of the best predictors of on-ice jump performance (N=9)

<table>
<thead>
<tr>
<th></th>
<th>Flight time$^a$ (beta ± SD)</th>
<th>Vertical jump height$^a$ (beta ± SD)</th>
<th>Peak power$^a$ (beta ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.T.A.R.S tuck jump</td>
<td>2 (0.042 ± 3.68)</td>
<td>2 (0.092 ± 3.68)</td>
<td>2 (0.170 ± 3.68)</td>
</tr>
<tr>
<td>Off-ice flight time</td>
<td>1 (-0.651 ± 0.05)</td>
<td>1 (-0.491 ± 0.05)</td>
<td>1 (-0.528 ± 0.05)</td>
</tr>
<tr>
<td>R Squared adjusted and SE</td>
<td>0.245 ± 0.025</td>
<td>0.020 ± 3.853</td>
<td>0.117 ± 370.396</td>
</tr>
</tbody>
</table>

$^a$ = On-ice jump performance variables adjusted for %difference. No significance (p ≤ 0.05) found.

Discussion

Research question answered. The purpose of this study was to investigate the relationship off-ice strength and power measures among pre-elite and elite figure skaters and the predictability that these measures may have on on-ice jump performance. The overarching research question that was answered in this study was “Are figure skater’s off-ice lower body strength and endurance and upper and lower body power measures predictors of their on-ice jump performances?” This question was answered through three primary research questions and the findings were as follows: (a) the S.T.A.R.S timed tuck jump assessment was the only tested off-ice performance measure that resulted in a positive relationship with all on-ice jump performance measures. Although, only weak to moderate positive interactions were found; (b) off-ice vertical jump flight-time was the best predictor of on-ice jump performance; and (c) 24% of the variance in on-ice vertical jump flight-time, 11.7% of the variance in on-ice vertical jump peak power, and 2% of
the variance in on-ice vertical jump height were accounted for by the off-ice vertical jump flight-time and the S.T.A.R.S. tuck jump assessment.

**Participant’s descriptive statistics.** The participant descriptive statistics found in this study (N = 8 figure skaters: 14.3±1.8 years; 158.5±5.0cm; 48.9±7.16kg) were similar to those found by Podolsky et al who had 8 female figure skaters 14.7 ± 1.6 years, 158.5 ± 5.0cm, and 53.4 ± 4.6kg. Participant’s on-ice average training time of 18.3 ± 3.2 hours/week was similar to findings of Kjaer et al where elite level figure skaters spent approximately 23 ± 4 hours/week on-ice training. These finding indicate that the sample of figure skaters used in this study may be similar to those of the larger figure skating community.

**On-ice descriptive statistics.** The average on-ice vertical jump flight-time for the axel jump was found to be 0.398 ± 0.063 sec. which is similar to the findings of Hunnicut et al. Before six weeks of plyometric training, figure skater’s on-ice waltz-jump (180 revolution jump) flight-times were approximately 0.362 sec. Although, these are two different jumps the timing similarity may be explained by research performed by King et al, where they found figure skater’s jump flight-time to be dependent on the highest revolution jump that they could perform.

On-ice average vertical jump height was found to be 27.9 ± 3.9cm. To our knowledge, there has only been one other study that has reported on-ice jump height in figure skaters; however, this study was done on elite male figure skaters and, therefore, the results cannot be compared to our study.
Vertical jump peak power from the Sayers Equation\textsuperscript{35} resulted in a mean power output of 2,011.2 ± 394.1 watts. Hunnicutt et al\textsuperscript{8} tested synchronized figure skaters peak power, in a plyometric performance study, but they did not report specific peak power numbers. To the knowledge of the researchers’, there has not been any other study done on figure skates that looked at on-ice vertical jump peak power.

\textbf{Off-ice descriptive statistics.} Of the off-ice variables tested, only off-ice vertical jump height and the S.T.A.R.S tuck jump assessment have been researched in figure skaters. Although, research on the S.T.A.R.S tuck jump assessment has only looked at normative data collection, and to our knowledge there has not been any published research looking at the correlation of this test to on-ice performance in figure skaters. Off-ice mean vertical jump height was found to be ~36cm, this is ~10cm lower than that reported in two adult synchronized figure skaters studies,\textsuperscript{8,13} which is an expected comparison as this is a different age group than that of our study. The mean S.T.A.R.S. tuck jump result of 46 jumps for our study fell within the mean USFSA, novice to senior figure skating freestyle level, normative data interval range of 42-49 jumps. This may indicate that the participants were familiar with this test and that they are up to par with other figure skaters in this assessment.

\textbf{Dartfish and force plate comparison.} Off-ice Dartfish\textsuperscript{®} vertical jump flight-time and jump height were found to be different when compared to the off-ice force plate flight-time and jump height. Pearson Correlation between these two testing measures and jump height showed significant very strong positive associations ($r = 0.93$, $p \leq 0.05$) and between vertical jump flight-time showed a moderate negative correlation ($r = -0.51$, $p \leq$
This indicates that Dartfish® may be a valid tool in assessing vertical jump flight-time. Therefore, this method could be used to assess on-ice performance measures.

**Characteristics of figure skaters.** Statistically significant negative correlations were found between participants’ height descriptive statistics and on-ice vertical jump flight-time and jump height. Therefore, the shorter the figure skater the greater their on-ice vertical jump flight-time. This finding supports observations by Nigg and Herzog that jump height is inversely related to an individual’s height. A moderate negative correlation was found between the ages that figure skaters stated skating and their on-ice jump flight-time, which indicates that figure skaters who begin skating at a younger age may have the ability to stay in the air longer, when jumping compared to those who began skating at an older age. This is consistent with an assumption by Smith who speculates how most successful figure skaters specialize in the sport of figure skating between the ages of 6-8.

**Ground reaction force.** Off-ice vertical jump GRF was found to be 3.2 x figure skaters body weight, which is similar to the results of found by Saunders et al. They found mean off-ice GRF for figure skaters to be 3.5 x body weight. On-ice GRF has been reported to be as high as 5-6.5 x a figure skater’s body weight, however, this is not something that our study was able to assess. High forces placed on the body from repetitive on-ice jump landing impacts can lead to overuse injuries, if proper rest and recovery time is not taken.

**Off-ice and on-ice relationships.** To our knowledge, our study was the first study to look at on-ice jump performance through the lens of vertical jump flight-time, peak
power, and height. These three on-ice performance variables will all be individually discussed as they related to the off-ice performance variables in this study.

_Flight-time._ A moderate positive correlation was found between the S.T.A.R.S. tuck jump assessment and figure skaters on-ice vertical jump flight-time \((r = 0.51)\). This showed that as the number of tuck jumps increased so did figure skaters on-ice vertical jump flight-time. This is the only off-ice performance testing variable that resulted in a positive correlation with on-ice flight-time. Research for the S.T.A.R.S tuck jump assessment has been limited to normative data collection by the USFSA and to our knowledge has not been published or assessed in terms of on-ice performance in figure skaters.\textsuperscript{44} Strong negative correlations were found between: on-ice vertical jump flight-time and off-ice flight time, long jump, and peak power. Indicating that as on-ice flight-time increased off-ice performance variables decreased. This was not an expected result and is not backed by the limited previous research between off-ice and on-ice performance variables. Bower et al\textsuperscript{13} and Podolsky et al\textsuperscript{9} found in their studies that on-ice performance variables improved as off-ice variables improved. The findings within our study may be the result of having a small sample size, which allows for a greater dispersion of testing results. However, only further investigation can determine whether the off-ice variables tested in our study are indicative of on-ice jump performance.

_Jump height._ The results of this study found weak to moderate negative correlations between on-ice vertical jump height and off-ice long jump \((r = -0.647)\), overhead toss \((r = -0.626)\), and vertical jump height \((r = -0.408)\). All of the pervious listed off-ice variables are indicators of participant’s upper and lower body strength and power measures.\textsuperscript{8,38} Increased strength has been shown to improve off-ice vertical jump height
and long jump. It has been suggested that increased strength is an important factor in increasing jump height. Podolsky et al found strong positive correlations between on-ice jump height and strength, during knee extension and shoulder abduction in single axel jumps (N = 18). Our study used dynamic strength assessments, while Podolsky et al used isokinetic strength assessments. The use of an isokinetic dynamometer, as a measurement of strength, creates an issue for the practical implications of this study, in terms of cost and availability of this equipment. Perhaps, our results are indicative of this differing in assessments or due to a lack of statistical power. More research is warranted looking at the correlation between off-ice strength and power measures and on-ice jump performance.

Peak Power. The background of power as related to jump performance has been discussed in figure skating literature, but, to our knowledge, has never been looked at in terms of off-ice performance measures. Based on professional opinion, Jaworski, a physician suggested that figure skater’s main focus off-ice should be to improve power, speed, and flexibility, while simultaneously gaining strength. Poe et al also suggests that figure skaters need to increase their off-ice power in order to increase on-ice jump performance and help to possibly decrease on-ice related injuries that are received as a result of learning new jumps. These opinions have only focused on the need for improving off-ice power in figure skaters in order to improve on-ice jump performance, however, they have not defined what on-ice jump performance is. In this study, we defined on-ice jump performance based on the definition by Hunnicut et al which is jump flight-time, height, and peak power. The results from this study showed strong negative correlations between off-ice vertical jump peak power (r = -0.544), vertical jump
height \((r = -0.661)\), and flight-time \((r = -0.556)\) and on-ice vertical jump peak power. This was not an expected result as increases in strength has been associated with increased peak power outputs,\(^{46}\) although, this has only been shown in off-ice performance and has yet to be demonstrated when looking at on-ice jump performance.

**On-ice jump predictability.** Off-ice vertical jump flight-time and the S.T.A.R.S. tuck jump assessment were the only off-ice variables that were not found to be highly correlated to other off-ice performance variables; thus, these were the only two variables that were looked at in terms of predictability to on-ice jump performance. It was found that \(2-24.5\%\) of total variance in on-ice performance variables could be accounted for by off-ice vertical jump flight-time and the S.T.A.R.S. tuck jump assessment. Therefore, on-ice flight-time has the greatest predictability, when looking at figure skaters off-ice vertical jump flight-time and the S.T.A.R.S. tuck jump assessment. When compared to the off-ice S.T.A.R.S. tuck jump assessment (beta values for on-ice performance = \(0.042 \pm 3.68\) flight-time; \(0.092 \pm 3.68\) jump height; \(0.170 \pm 3.68\) peak power), off-ice flight-time was found to be a better predictor of on-ice jump performance (beta values for on-ice performance = \(-0.651 \pm 0.05\) flight-time; \(-0.491 \pm 0.05\) jump height; \(-0.528 \pm 0.05\) peak power). This finding indicates that off-ice vertical jump flight-time may be what strength and conditioning coaches should assess to determine if their strength and conditioning regiments are effecting on-ice jump performance. Previous research has not been done looking specifically at the predictability of off-ice performance variables and their ability to predict on-ice jump performance; however, there has been one study done by Bower et al\(^{13}\) that looked at the predictability of off-ice performance measure and the relatability to on-ice speed, acceleration, and skating endurance in figure skaters. They
concluded that off-ice slide-board was the single best predictor of on-ice speed and acceleration.

**Conclusion.** The age that a figure skater begins skating and their current height may be factors affecting their on-ice vertical jump flight-time. All off-ice strength and power measures, besides the S.T.A.R.S. tuck jump assessment, were found to have negative correlations to on-ice jump performance, and thus, may not be the best predictors in on-ice jump performance. With its positive correlation to on-ice jump performance, the S.T.A.R.S. tuck jump assessment may be an off-ice testing measure that strength and conditioning coaches can use to assess their strength and conditioning regiments. Off-ice vertical jump flight-time was found to be the best of on-ice jump performance, when compared to the S.T.A.R.S. tuck jump assessment. Both the off-ice vertical jump flight-time and the S.T.A.R.S. tuck jump assessment were not found to be significant predictors of on-ice jump performance; however, they were found to account for 2-24.5% of the variances in the on-ice jump performance variables. On-ice flight-time had the greatest amount of variance explained by off-ice vertical jump flight-time and the S.T.A.R.S. tuck jump assessment and thus, may be the on-ice jump performance variable that should be looked at when assessing off-ice performance variables. The small sample size of this study does not allow the results to be implied to the larger figure skating population and, therefore, the findings of this study warrant the need for further research on the subject of off-ice strength and power measures and on-ice jump performance measures.

**Practical implications.** The results of this study support the usage of the off-ice S.T.A.R.S tuck jump assessment as a possible means of predicting on-ice vertical jump
flight-time performance. This test may be a tool that can be used as a progress assessment for strength and conditioning programs, and possibly indicate if the training program is having an impact on on-ice jump performance.
REFERENCES


20. Boldt DE. A descriptive analysis of the joint reaction forces and the ground reaction forces in the lower limb during the landing of a triple toe loop (Thesis). Winnipeg, Manitoba: University of Manitoba; 1993.


APPENDIX A

INFORMED CONSENT-ADULT

University of Colorado Colorado Springs (UCCS)
Adult Consent to be a Research Subject

**Title:** An investigation of off-ice strength and power measures among figure skaters: Predictability of on-ice flight-time and jump height.

**Principal Investigator and Examiner:** Elizabeth Heil

**Introduction**
You are being asked to participate in a research study. This form is designed to tell you everything you need to think about before you decide to consent (agree) to be or not to be in the study. The principal investigator will describe this study to you and answer any questions.

**It is entirely your choice. If you decide to take part, you can change your mind later and withdraw from the research study.**

Before making your decision:
- Please carefully read this form or have it read to you.
- Please ask questions about anything that is not clear.

Feel free to take your time thinking about whether you would like to participate. By signing this form you will not give up any legal rights.

**Study Overview**
This study plans to learn more about how off-ice power measurements relate to on-ice jump height and flight-time in single figure skaters.

**Procedures**
You are being asked to be in this research study because you are currently in one figure skating competition per year, currently training on-ice at least six hours per/week, and have passed the United States Figure Skating Association (USFSA) Juvenile Freestyle test. You will be asked to allow collection of measurements such as height, weight, body composition and off-ice power measurements (standing long jump, overhead medicine ball throw, and STARS tuck up protocol). Additionally, you will be asked to perform three axel jumps on ice that will be video recorded. Your participation may take up to 45 minutes (15 minutes on one day and 30 minutes on another day.)

**Other people in this study**
There will be up to 25 figure skaters participating in this study.

**Risks and Discomforts**
The risks in this study are no greater than the risks you would encounter during your normal training for figure skating. Therefore the risks you could sustain are injuries that are associated with physical exertion figure skating training on-ice and off-ice at altitude.

**Benefits**
This study is designed for the researcher to learn more about how collected information may impact on-ice jump height and flight-time, which may be incorporated into sports performance programs.

**Compensation** None Provided

**Confidentiality**
Data will remain de-identified throughout the entire process; forms and camera with videos will be stored in a locked cabinet in the faculty advisors office. Only the principal investigator, Co-PI and Additional Personnel will have access to the sheet with the association between subjects' numbers and names. Any publication of the results of this study will not include your name.

Certain offices and people other than the researchers may have access to study records. Government agencies and the University of Colorado-Colorado Springs (UCCS) employees overseeing proper study conduct may look at your study records. These offices include the UCCS Institutional Review Board and UCCS Office of Sponsored Programs. UCCS will keep any research records confidential to the extent allowed by law. A study number rather than participant’s names will be used on study records wherever possible. Study records may be subject to disclosure pursuant to a court order, subpoena, law or regulation.

**Voluntary Participation and Withdrawal from the Study**
Taking part in this study is voluntary. You have the right to leave a study at any time without penalty. You may refuse to do any procedures you do not feel comfortable with. If you withdraw from the study, you may request that your research information not be used by contacting the Principal Investigator listed below.

**Contact Information**
Contact Elizabeth Heil via email at lheil@uccs.edu:
- If you have any questions about this study or the research, or
- If you have questions, concerns, or complaints about the research.

Contact the Research Compliance Specialist at 719-255-3903 or via email at irb@uccs.edu:
- If you have questions about your rights as a research participant, or
- If you have questions, concerns, or complaints about the research.
Consent

A copy of this consent form will be provided to you. I understand the above information and voluntarily consent to participate in the research. By signing this consent, I am confirming that I am 18 years of age or older.

Signature of Participant __________________________________________
Date____________
APPENDIX B

INFORMED CONSENT-CHILD

University of Colorado Colorado Springs (UCCS)
Child Consent to be a Research Subject

Title: An investigation of off-ice strength and power measures among figure skaters: Predictability of on-ice flight-time and jump height.

Principal Investigator and Examiner: Elizabeth Heil

Introduction

Your child is being asked to participate in a research study. This form is designed to tell you everything you need to think about before you give permission for your child to be or not to be in the study. The principal investigator will describe this study to you and answer any questions. It is entirely your choice. If you decide for your child to take part, you can change your mind later and withdraw them from the research study.

Before making your decision:
- Please carefully read this form or have it read to you.
- Please ask questions about anything that is not clear.

Feel free to take your time thinking about whether you would like your child to participate. By signing this form you will not give up any legal rights for your child.

Study Overview

This study plans to learn more about how off-ice power measurements relate to on-ice jump height and flight-time in single figure skaters.

Procedures

Your child is being asked to be in this research study because he/she is currently in one figure skating competition per year, currently training on-ice at least six hours per/week, and have passed the United States Figure Skating Association (USFSA) Juvenile Freestyle test. You will be asked to allow collection of measurements such as height, weight, body composition and off-ice power measurements (standing long jump, overhead medicine ball throw, and STARS tuck up protocol) on your child. Additionally, your child will be asked to perform three axel jumps on ice that will be video recorded. Your child’s participation may take up to 45 minutes (15 minutes on one day and 30 minutes on another day.)

Other people in this study

There will be up to 25 figure skaters participating in this study.

Risks and Discomforts

The risks in this study are no greater than the risks your child would encounter during their normal training for figure skating. Therefore the risks your child could sustain are injuries that are associated with physical exertion figure skating training on-ice and off-ice at altitude.
Benefits
This study is designed for the researcher to learn more about how collected information may impact on-ice jump height and flight-time, which may be incorporated into sports performance programs.

Compensation
None Provided

Confidentiality
Data will remain de-identified throughout the entire process; forms and camera with videos will be stored in a locked cabinet in the faculty advisors office. Only the principal investigator, Co-PI and Additional Personnel will have access to the sheet with the association between subjects' numbers and names. Any publication of the results of this study will not include your name.

Certain offices and people other than the researchers may have access to study records. Government agencies and the University of Colorado-Colorado Springs (UCCS) employees overseeing proper study conduct may look at your study records. These offices include the UCCS Institutional Review Board and UCCS Office of Sponsored Programs. UCCS will keep any research records confidential to the extent allowed by law. A study number rather than participant’s names will be used on study records wherever possible. Study records may be subject to disclosure pursuant to a court order, subpoena, law or regulation.

Voluntary Participation and Withdrawal from the Study
Taking part in this study is voluntary. Your child has the right to leave a study at any time without penalty. Your child may refuse to do any procedures they do not feel comfortable with. If your child withdraws from the study, you may request that your child’s research information not be used by contacting the Principal Investigator listed below.

Contact Information
Contact Elizabeth Heil via email at lheil@uccs.edu:

- If you have any questions about this study or the research, or
- If you have questions, concerns, or complaints about the research.

Contact the Research Compliance Specialist at 719-255-3903 or via email at irb@uccs.edu:

- If you have questions about your rights as a research participant, or
- If you have questions, concerns, or complaints about the research.

Consent
A copy of this consent form will be provided to you. I understand the above information and by signing this form give permission for my child to participate in the research.
Signature of Parent/Guardian___________________________Date_________
APPENDIX C

ASSENT TO BE IN THE STUDY

1. My name is Elizabeth Heil and I am a college student at the University of Colorado-
Colorado Springs.

2. We are asking you to take part in a research study. We are trying to learn more about
how training off-ice might improve on-ice jumps for figure skaters.

3. If you agree to be in the study, you will be asked to answer some questions to help us
determine if you are healthy enough to be part of the study and then come to two
sessions. The first will take about 30 minutes and we will get information like body
weight, height and body fat using a special scale that you stand on. We will also ask you
to perform some jumps on a piece of equipment called a force plate and toss a medicine
ball. The second day will take about 15 minutes. We will video record you completing
three successful axel jumps on-ice.

4. This study will not purposely hurt anyone taking part. There is a chance that you could
get hurt but not any more than what might happen with your normal training.

5. You will find out how high, long, and fast that you can jump and how powerful your
arms and legs are. This study will help figure skaters, coaches, and strength/exercise
coaches decide what type of training figure skaters should do off-ice to help them have
better jumps on-ice.

6. Please talk to your parents about this study before you decide if you want to be in the
study. We will also ask your parents if it is all right with them for you to be in the study.
If your parents say that you can be in the study, you can still decide not to be in the study.

7. You can ask me any questions that you have about this study and I will try to answer
them for you. If you have questions that you think of later, you can email me at
lheil@uccs.edu.

8. Taking part in this study is up to you. You do not have to be in the study. No one will
be mad at you if you don’t want to do this. If you want to be in the study, you can say
yes. If you say yes, but change your mind later, you can stop any time you want.

Please mark one of the choices below to tell us what you want to do:

___ No, I do not want to be in this study. ___ Yes, I want to be in this study.

___________________________                                                      ___________
Write your name here                                                                               Date
Figure Skaters Needed!!

FEBRUARY 2016
FIGURE SKATING POWER
AND JUMP TESTING

Eligibility:
Figure skaters aged 8-20 years, currently in one figure skating competition per year, currently training on-ice at least six hours per/week, and have passed the United States Figure Skating Association (USFSA) Juvenile Freestyle test.

Purpose:
To establish a scientific basis for figure skaters to perform off-ice strength and power training as it relates to on-ice figure skating jump performance.

On-Ice and Off-ice Testing

Compensation:
There will not be any compensation for participating in the study, although the benefits are listed below.

Benefits:
Learn Your......
Flight-Time!
Jump Height!
Jump Power!
Jump Endurance!
Ground Reaction Force!

TIME COMMITMENT:
APPROXIMATELY 45 MINUTES (TWO TESTING SESSIONS 15 MINUTES AND 30 MINUTES)

UNIVERSITY OF COLORADO COLORADO SPRINGS

Where:
Colorado Sports Center
16240 Old Denver Rd,
Monument, CO 80132

If you are interested or have any questions.....

Please contact: Lizzie
At: lheil@uccs.edu
Or 715-965-4384
APPENDIX E

DATA COLLECTION SHEET

Date_________________________                      Subject ID: ________

**Anthropometrics:**
- Age: ___________ years
- Height: __________ cm
- Mass of figure skates: _______ kg
- Mass: ___________ kg
- Body Fat: ________ %
- Gender: Male __ Female

**Off-Ice Testing:**

**Off-Ice Vertical Jump Height**
- Trial 1: ________________cm
- Trial 2: ________________cm
- Trial 3: ________________cm
- Average Jump: ________________cm
- Flight Time: _________________sec
- Power (Sayers) ____________
- Peak Power (average) ____________
- Ground Reaction Force________

**Off-Ice Standing Long Jump Distance**

**On-Ice Testing:**

**Date: ____________**

**Axel Jump**

- Trial 1:
  - ___________cm (Vertical)
  - ______________sec (flight-time)
- Trial 2:
  - ___________cm (Vertical)
  - ______________sec (flight-time)
- Trial 3:
  - ___________cm (Vertical)
  - ______________sec (flight-time)

Power (Sayers) (average) ________________
APPENDIX F

QUESTIONNAIRE

Figure Skating Questionnaire

The University of Colorado Colorado Springs (UCCS) Graduate Health Sciences student, of the "Sports Medicine- Strength and Conditioning Master's program", is conducting a thesis on whether Off-Ice Power Measurements are Predictors of On-Ice Jump Performance in Single Figure Skaters, to complete the degree research requirements for the degree. Please answer the following questions below to help with fulfill this requirement. Questions will examine figure skating history, training status, jump proficiency, and current freestyle level. This survey will take approximately 5 to 10 minutes to complete. You have the right to elect not to answer this survey, or any questions within it. However, the more complete your answers are, the more your survey will be have value to understanding the relationship between off-ice and on-ice performance measures in figure skaters. Answering the survey will qualify as your consent to use this information in the database for assessment. Thank you for your participation! If you have any questions, please contact, Lizzie Heil at lheil@uccs.edu.

Figure Skating Performance

1. What is the **highest** freestyle test that you have **passed**? *Circle one.*

   a. No Test
   b. Pre-Preliminary
   c. Preliminary
   d. Pre-Juvenile
   e. Juvenile
   f. Intermediate
   g. Novice
   h. Junior
   i. Senior
   Other __________________________

2. Which of the following jumps can you consistently land (minimal falls; without two foot landings and hand(s) touching ground)? *Circle all that apply.*

   Waltz Jump       Axel       Triple Axel
   Single Salchow   Double Salchow Triple Salchow
   Single Toe Loop  Double Toe Loop Triple Toe Loop
   Single Loop      Double Loop   Triple Loop
   Single Flip      Double Flip   Triple Flip
   Single Lutz      Double Lutz   Triple Lutz
   Other__________________________
3. At what age did you first begin figure skating?
   ______ Years of age

4. What is your current training status? Circle one.
   a. Competitive (competing in at least one figure skating competition each year)
   b. Non-competitive (do not compete in any figure skating competitions)

5. In an average week, how many days do you spend on-ice training?
   ______ day(s)

6. During each day that you spend on-ice training, how much time do you spend on average training on-ice?
   ______ hour(s) ______ minute(s)

7. Have you suffered any injuries legs in the past 14 days that made you miss 3 or more days of on-ice training? Circle one.
   a. Yes
   b. No
   *If yes, please explain state type of injury and treatment___________________________________

8. Do you participate in any off-ice sport-specific activities? Circle all that apply.
   a. Ballet
   b. Trampoline
   c. Off-ice jump class
   d. Gymnastics
   e. Flexibility classes
g. Strength Training
Other ________________________________

9. How many off-ice sport-specific activities sessions (an activity lasting 20 minutes or more) do you complete each week?

______session(s)

On average, how long was each session

______hour(s) ______minute(s)

10. Do you participate in a structured off-ice strength and conditioning program?
   Circle one. If yes go to question 11, if no move to question 13.
   a. Yes
   b. No

Off-ice Training-continued

11. If answered yes to question 10, how many days/week do you train off-ice?

______day(s)

12. Of the days that you train/week in question 11, how much time do you spend training each day?

______hour(s) ______minute(s)

Demographics


   a. Elementary school
   b. Middle school
   c. High school
   d. College
   e. Other___________________________________________________

14. What is your current schooling status

   a. Public or private school
   b. Homeschooled
   c. Other___________________________________________________
15. What is your ethnicity? *Circle all that apply.*

   f. Caucasian/White  
   g. African American  
   h. Hispanic  
   i. Asian  
   j. Native American/Pacific Islander  
   k. Other__________________________

16. What is your gender? *Circle one.*

   a. Male  
   b. Female  

17. What is your birth date?

   _______ month    _______ day    _______ year

Thank You!
From: Andrew Sherman  
Address: 16240 Old Denver Rd, Monument, CO 80132  
Email: shermanandrew@hotmail.com

Today's Date: 11/2/2015

To: Institutional Review Board  
Office of Sponsored Programs  
University of Colorado Colorado Springs  
1420 Austin Bluffs Park Way  
Colorado Springs, CO 80918

Dear UCCS IRB,

The purpose of this letter is to grant Elizabeth Heil and Dr. Craig Elder, at the University of Colorado Colorado Springs permission to conduct research at Colorado Sports Center. The project titled, “Are Off-Ice Power Measurements Predictors of On-Ice Jump Performance in Single Figure Skaters” entails use of the skating rink to gather on-ice jump variables and the 365 performance center to gather off-ice strength and power. Off-ice upper and lower body power testing and on-ice jump variables will be collected via approximately 25 figure skaters aged 8-20 years, to establish a scientific basis for figure skaters to preform off-ice strength and power training as it relates to on-ice figure skating jump performance.

After review of the study protocol, Andrew Sherman I do hereby grant permission for Elizabeth Heil and Dr. Craig Elder to conduct the research title “Are Off-Ice Power Measurements Predictors of On-Ice Jump Performance in Single Figure Skaters” at Colorado Sports Center.

Sincerely,

Andrew Sherman
APPENDIX H

PARQ FOR CHILDREN AGED 8-14

Physical Activity Readiness Questionnaire for Children 8-14 Years of Age

Child Name: _____________________ Parent/guardian name: _____________________________

Address: ____________________________________________________ ____________________

Child date of birth: __________________________

Child Current Age: __________________________

Emergency Contact Name and Relationship (e.g. father): ___________________________

Emergency Contact Number - ____________________________ _______________________

Health Questions

Does your child have or has he/she ever experienced any of the following (please circle Y/N)

1. High or low blood pressure Y / N
2. Elevated blood cholesterol Y / N
3. Diabetes Y / N
4. Chest pains brought on by physical exertion Y / N
5. Childhood epilepsy Y / N
6. Dizziness or fainting Y / N
7. A bone, joint or muscular problems with arthritis Y / N
8. Asthma or other respiratory problems Y / N
9. Any sustained injuries or illnesses Y / N
10. Any allergies Y / N
11. Is your child taking any medication? Y / N
12. Has your doctor ever advised your child not to exercise? Y / N
13. Is there any reason not mentioned above why any type of physical activity may not be for your child? Y / N If yes, please

explain ________________________________________________________________

If you have answered ‘Yes’ to any of the above questions, please provide full details here:

___________________________________________________ ________________________

___________________________________________________ ________________________

___________________________________________________ ________________________

___________________________________________________ ________________________

___________________________________________________ ________________________
In signing this form, I (the parent/guardian of the aforementioned child) affirm that I have read this form in its entirety and I have answered the questions accurately and to the best of my knowledge. I understand that my child is responsible for monitoring him or herself throughout the activity, and should any unusual symptoms occur, my child understands the importance of informing the researcher immediately.

Parent/guardian signature: ..............................................................

Date: ........................... Please print name: .................................................
APPENDIX I

PARQ FOR PARTICIPANTS AGED 15 AND UP

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

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

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

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

YES ☐ NO ☐

1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

2. Do you feel pain in your chest when you do physical activity?

3. In the past month, have you had chest pain when you were not doing physical activity?

4. Do you lose your balance because of dizziness or do you ever lose consciousness?

5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?

6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?

7. Do you know of any other reason why you should not do physical activity?

If you answered YES to one or more questions:

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

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

If you answered NO to all questions:

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

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

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

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

NAME ___________________________ SIGNATURE ___________________________ DATE ___________________________

SIGNATURE OF PARENT or Guardian (for participants under the age of majority) ___________________________ DATE ___________________________ WITNESS ___________________________ DATE ___________________________

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.
APPENDIX J

INSTITUTIONAL REVIEW BOARD APPROVAL

Thank you for submitting your Request for IRB Review. The protocol identified above has been reviewed according to the policies of this institution and the provisions of applicable federal regulations. The review category is noted above, along with the expiration date, if applicable. Please note that Renewals and Reports of Change may be reviewed as Expedited, provided there is no change to the risk level of the participants.

Once human participant research has been approved, it is the Principal Investigator’s (PI) responsibility to report any changes in research activity related to the project:

- The PI must provide the IRB with all protocol and consent form amendments and revisions.
  - The IRB must approve these changes prior to implementation.
- All advertisements recruiting study subjects must also receive prior approval by the IRB.
- The PI must promptly inform the IRB of all unanticipated serious adverse (within 24 hours). All unanticipated adverse events must be reported to the IRB within 1 week (see 45 CFR 46.103b(5)). Failure to comply with these federally mandated responsibilities may result in suspension or termination of the project.
- Renew study with the IRB prior to expiration.
- Notify the IRB when the study is complete

If you have any questions, please contact Michael Sanderson in the Office of Sponsored Programs at 719-255-3903 or irb@uccs.edu

Thank you for your concern about human subject protection issues, and good luck with your research.

Sincerely yours,

Deborah J. Kenny
UCCS IRB Chair