EXAMINING THE RELATIONSHIP BETWEEN PHYSICAL FITNESS AND ON-ICE PERFORMANCE IN DEVELOPMENTAL FIGURE SKATERS

by

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ABSTRACT

Objective: The purpose of this study was to examine the relationship between physical fitness and skill related fitness compared to on ice performance of developmental figure skaters.

Methods: A total of ten basic off-ice assessments were administered, including skill-related physical fitness tests of agility (T-Test, Hexagon Test), and balance (Stork Stand); as well as health-related physical fitness tests, including: flexibility (Seated Reach), muscular endurance (the One Minute Sit-Ups, One Minute Modified Push-Ups, the Plank), muscular strength (Hand Grip), and power (the Timed Tuck Jumps, Vertical Jump). On-ice assessments will include a speed test and acceleration test to determine skating ability, and assessments of four elements; the axel jump, the back spin, camel spin, and the sit spin.

Subjects: Twenty eight developmental female figure skaters between the ages of 6 and 14 who competed in the STAR 2, STAR 3, STAR 4, or STAR 5 categories as outlined by the BC Section Competition criteria (part of the Learn To Train Stage of the Skate Canada Long Term Athlete Development Model) were recruited.

Conclusions: Skaters in the axel group (n=9) performed significantly better in physical fitness tests of balance, muscular strength (vertical jump), muscular endurance (timed tuck jumps, sit-ups, plank), and flexibility (seated reach). As well, the axel skaters were stronger skaters (1-lap speed test and spin tests). Regression analysis showed correlations between vertical jump and the on-ice speed test, the 30-second timed tuck jumps and acceleration as well as the T-test for agility and the 1-lap speed test.

PREFACE

This dissertation is an original, intellectual work by Regan Taylor. Shannon Bredin was involved in the earlier stages and contributed as manuscript edits on Chapters 1-3 during the proposal. Maria Gallo and Lauren Couture contributed to manuscript edits for all chapters in the final review stages. Shayestah Jahanfar contributed by clarifying the statistical analyses.

Chapter 3 is a Systematic Review requiring its own separate abstract as a separate document within this thesis.

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LIST OF ABBREVIATIONS

LTAD Long Term Athlete Development Model

STARS (US Figure Skating) Standardized Testing of Athleticism to Recognize Skaters

STARS (Skate Canada - BC/YK Section) – Original – Skating, Tests, Awards, Recognition, or Group of Categories implemented by BC Section in accordance with LTAD Learn to Train Pilot Program

BC/YK (British Columbia and the Yukon)

NSO National Sport Organization

HR Heart Rate

CoP Centre of Pressure

VO_2 Volume of Oxygen uptake

ISU International Skating Union

NMT Neuromuscular Training

GLOSSARY

Early specialization sport: Early specialization sports include artistic and acrobatic sports such as gymnastics, diving, and figure skating. These differ from late specialization sports in that very complex skills are learned before puberty since they cannot be fully mastered if taught after puberty (Balyi, Way, Higgs, Norris, & Cardinal, 2014).

Freeskating: The portion of figure skating that involves combining elements such as jumps, spins, and other simple or complex moves.

Figures: A portion of skating that involved complex patterns on the ice mostly based on circles that incorporated various turns and edges.

Sampling Years: The first stage of sport involvement occurs between the ages of 6 and 13 for all the participants when children should be involved in a variety of sport related activities to develop a physical literacy base.

Skate Canada: The National governing body of figure skating.

BC/YK Section The Provincial governing body of figure skating.

Ecological Perspective: The network of interactions among organisms and between organisms and their environment.

Deterministic Model: A model that shows the outcome based on a set of underlying parameters.

Group Embedded Figures Test: The Group Embedded Figures Test (GEFT) was developed for research into cognitive functioning and is a twenty-five item assessment about field dependence-independence.

Field dependence-independence: A concept in the field of cognitive where people who exhibit field dependence tend to rely on information provided by the outer world, the field or frame of a situation and their own cognition.

Freeside: The side of the skater that is not their landing foot side. For a skater that rotates counter-clockwise, this would be the left side.

Skating Side: The side of the skater that is the landing foot side. For a skater that rotates counter-clockwise, this would be the right side.

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I would like to acknowledge the support of my family as well as my volunteers who helped me on the day of testing as well as the skaters for participating so that I could expand my coaching knowledge.

CHAPTER ONE THESIS INTRODUCTION

1.1 Chapter Introduction

The sport of figure skating originated from a complicated history that transformed the physical demands of the sport and influenced the nature of its participants. The foundations of the sport have evolved to increasing levels of technical difficulty that were unimaginable during the sports' origins. Top skaters require unprecedented amounts of physical fitness, and the fatigue this causes on skaters' bodies has augmented the numbers of figure skating related injuries (Bloch, 1999; Brock & Striowski, 1986; S Dubravcic-Simunjak, Kuipers, Moran, Simunjak, & Pecina, 2006; Sandra Dubravcic-Simunjak, Pecina, Kuipers, Moran, & Haspl, 2003; Ferrara & Hollingsworth, 2007; Foley & Bird, 2013; Fortin & Roberts, 2003; Kjaer & Larsson, 1992; Lipetz & Kruse, 2000; Pecina, Bohanic, & Dubravcic, 1990; Porter, 2013; Smith & Ludington, 1989). Physical characteristics of modern figure skaters would be almost incomparable to those skaters in the earliest years of the sport's evolution.

The sport of figure skating has undergone substantial transitions since its roots from an emphasis on the technical skill required to perform the intricate carvings left on the ice, to artistry, and then to an increasing emphasis on athleticism (D. King, Arnold, & Smith, 1994). The physical demands of the sport have progressed alongside the changes to its participants and rules. Modern figure skating has become an early specialization sport requiring children to participate in many hours of training in order to master the required skills at early ages. Figure skating now considered a tariff sport, in which the difficulty and complexity, of moves lead to the potential for higher marks and the competitor has the power to select the maneuvers they want to perform (Foley & Bird, 2013).

The increased performance demands, complexity and volume of training as well as a broadening spectrum of injury indicate a need in modern figure skating for focused research programs to identify optimal methods of training and injury management. Skate Canada is among the many sport-governing bodies in Canada that have been developing materials to guide coaches and parents in the provision of appropriate training environments for the optimal development of young athletes. This pathway is known as the Long Term Athlete Development Model (LTAD)(Sport Canada, 2009). The LTAD is based on the maturation and developmental age of the child, rather than the chronological age and frameworks a progressive pathway based on training, competition and recovery. However, little is known about the requirements and physical demands that the outlined development pathway requires.

1.2 The Historical Evolution of the Sport

Figure skating began as a means of transportation along frozen lakes and canals in Europe in the 1800's (Hines, 2006b). It grew in popularity as a recreational activity among the aristocracy in the 1900's as skating movements began to incorporate more expressive and free moving elements. Figure skating also developed into a sport, wherein the International Skating Union (ISU) was established in 1892 in the Netherlands. The ISU is still the world governing body of all ice skating sports including speed skating. Figure skating is the first winter sport to be included in an Olympic Games making its debut in the London Summer Games of 1908, 16 years prior to the first Winter Olympic Games in Chamonix, France ("Figure Skating Equipment and History," 2013). Today figure skating is practiced and regulated in over 55 nations (Moran, 2000). Many young skaters all over the world are drawn to the sport because of the attention of competition on television along with the costumes and make up, and the fun of performing a routine to music. While the sport of figure skating has become quite popular, little is known about the physical demands that the sport has on young adolescent or children's bodies.

Early competitions in the sport were centered on the complex and interesting patterns that the skater carved into the ice with their blades, referred to as *special figures*. The judging of figures was based on the difficulty and artistic nature of the pattern left on the ice (Hines, 2006b). While performing these complex figures required exceptional balance and control, the outward appearance of the skater was jerky and lacked grace. As competitions between countries became more formalized, figures were awarded a scoring value (Hines, 2006d).

Modern 'freeskating' contentiously evolved in as a clash between the technical difficulty of performing the special figures and the elegant style of skating 'free' to the music. During the

1860s, an American skater and ballet dancer, Jackson Haines, was the first to add music to his routine along with his balletic choreography. Though controversial at first, this form of skating became very popular in Europe alongside the formation of many skating championships. Many leagues and clubs were formed based on this performance art style of skating. During the 1920s and 1930s, the sport evolved further and a number of new free skating elements were introduced, including jumps, spins, spirals, and dance steps. 'Freeskating' became internationally known as multiple figures were connected in a continuous program set to music (Hines, 2006c) similar to the freeskate programs seen in competition today. However, jumping didn't become an important part of skating until the 1930s (Hines, 2006a). The axel jump, first performed by Axel Paulsen in 1882 was presented as his special figure (Hines, 2006c) and was not part of routine or even set to music. But as the sport was evolving with the connecting steps, skaters began adding these jumps and other elements such as spins and field moves into their routines. As the sport continued to grow, more emphasis on the element program (a program to music including various jump, spins and other elements) over the compulsory figures began to emerge.

In 1968, the ISU began reducing the weight of the figures as television coverage of the sport increased. The figures portion of the competition, which was always weighted more heavily than the freeskate program, was never shown on television and viewing audiences were left confused when strong freeskaters lost to opponents who had placed higher during the figures portion of the competition. The short program was then introduced in 1973, creating a competition format that now gave stronger freeskaters a slight advantage. For many years, the competition format consisted of three segments, performed in the following order: figures, the short program, and the free program. However, by 1990, the compulsory figures were eliminated completely from international competition. This change in format was based on a rising pressure on television ratings and to take into consideration ISU countries with less access to ice time.

As the sport progressed and changed, so did the types of skaters who participated in the sport. Traditionally, only men were allowed to compete, with the first women skater, Madge Syers competing in the 1902 World Championships (finishing second among the men). A separate ladies event was added to the World Championships in 1906. Competitions involving special figures, did not demand much athleticism; rather, an emphasis on balance and precision was required for successful performance, which took many years of training. Technical advances in figure skating occurred in the sport between the two world wars as skaters continued to try new things and develop their athleticism. From this, figure skating developed a unique balance between this athleticism and artistry of the routines (Hines, 2006a).

The artistry of the sport has continued to progress incorporating modern themes, music, and stories but not to the same degree as the increase in athleticism and technical requirements. The technical advances most recognizable by figure skating audiences has been the addition of more revolutions performed in jumps. Dick Button, the 1948 and 1952 Olympic Champion, was the first skater to perform the double axel and triple loop jumps in competition. In 1988, Kurt Browning landed the first quadruple toe-loop during a World Championship; and in 1989, Midori Ito landed the first triple axel by a lady in competition. To reach modern world class levels, male skaters require mastery of all triple jumps and at least one quadruple jump.

Ladies require mastery of all triples with the exception of the triple axel. Though the number and difficulty of the jumps increased skaters were not necessarily rewarded for it by the judges.

The most recent and most significant changes to sport have occurred in the last decade because of changes to how the sport is judged. Figure skating was traditionally judged based on the ‘total package’ of the performance. Under the 6.0 system, judges awarded one mark for the ‘technical merit’ of the program (the combination of jumps, spins, footwork, and the quality of the skating) and another mark for ‘artistic impression’ (the ability of the skater to use the music and choreography together into the performance). Judging scandals and corruption ruled skating for many years until the 2002 Salt Lake City Winter Olympics in which a French judge admitted to fixing scores (“Ice Skate,” n.d.). This led to an extreme change in how performances are scored. Individual elements within a program now receive a point value, which is determined by a completely separate panel of officials known as the ‘technical panel’. The judging panel still ranks the quality of the elements within the program to a specific set of criteria. This new system of judging has pushed the athletic requirements of the sport to new levels; for example, skaters strive to perform jumps with increasing difficulty to achieve greater point values. Similarly, skaters attempt more difficult spins (based on position), which require greater strength and flexibility. Footwork sequences have become increasingly technical requiring greater balance and skill. Furthermore, the skater is required to continuously sequence the various elements with complex choreography, all the while making it look effortless.

The focus of improving jumping ability in figure skating saw a decline in the artistry over the 1980's (Hines, 2006a). However since 2004, the new ISU rules of judging have brought the artistry up to new levels while continuing to demand higher athleticism from skaters to perform programs comprised only of triple jumps and higher at the international levels. Spin positions have been taken to new levels with the implementation of the new judging system. Whereas skaters before were judged subjectively on the difficulty and aesthetic positions of the spins, with the points awarded as part of the program; blended with all the jumps, field moves and connecting steps for two separate marks. Within the new ISU scoring system, spins receive more points for increasing difficulty of the positions so skaters are increasing their flexibility and strength to gain more points.

With the removal of figures, there has been a consistent decrease in skating age within the realm of high performance. Champions are achieving this status at younger ages and completing more and more difficult moves to obtain marks. While skating champions may have previously retained their titles for close to a decade, the increased physical demands of the sport are seeing many more accomplished skaters retiring earlier in their careers because the training demands required to be successful in the sport are very arduous (Foley & Bird, 2013). World class figure skating competitors must be in top physical condition. Johnny Heater, an MC for the National Figure Skating Championships, once said that "being a good figure skater required the balance of a tightrope walker, the endurance of a marathon runner, the aggressiveness of a football player, the agility of a wrestler, the nerves of a golfer, the flexibility of a gymnast, and the grace of a ballet dancer" (McMaster, Liddle, & Walsh, 1979). Therefore, a successful figure skater requires a solid physical foundation among many other qualities.

1.3 Rationale for Study

Figure Skating is a sport with consistent popularity. In 2012-2013 there was over 183,000 registered skating members in Canada (Skate Canada, 2013). Over 85 % of the registered figure skaters in Canada are currently in the new STAR categories of skater competition development (Skate Canada, 2013). This developmental stage requires skaters to learn all the basic spins and single jumps with the conclusion of the axel jump. As the greatest portion of skaters falls beneath these skills, many skaters are not mastering these critical elements that will allow them to proceed further into the sport.

Within Skate Canada, 50% of the skaters are between the ages of 9 and 13 (Skate Canada, 2013). Moreover, there is a rapid decline in participation in the sport around the age of 14. Therefore, it is important to better understand the reasons for this rapid decline, as well as identifying developmentally appropriate strategies for keeping young skaters involved the sport.

Amongst the current literature and research surrounding figure skaters, the majority has investigated the physical characteristics and capabilities of the elite figure skaters which make up a small portion of the sport's participation. It is important to understand the demands of the sport from a developmental perspective to recognize how skaters may reach the elite level while ensuring proper maturation and development without significant and damaging injuries.

1.3.1 Researcher Positionality

I am currently a Level 4 certified coach with Skate Canada, with an Advanced Coaching Diploma through the National Coaching Institute, and I hold a Chartered Professional Coach affiliation with the Coaches of Canada. Over the past few years I have begun to question long held coaching methods and practices within my sport. During 13 years of coaching, I have seen many skaters struggle through months and years of learning the axel jump. Countless hours have been spent by many skaters and their coaches, practicing in one corner of the ice, and attempting axels over and over again. I have wondered if all that expensive lesson time could be better spent by creating the physical foundations required for the skills so that the skaters might accomplish the axel within a shorter amount of instructional time.

The axel is one the biggest technical skills that many skaters never achieve, and is a pivotal milestone for development. An axel requires a great deal of relative strength and agility for the take-off as well as balance, and coordination, and core strength for the landing. Of course, technique is important but it can only go so far to make up for these deficits. The less physical capability you have, the more precise and efficient your technique has to be. This adds up to more costs in ice time and lessons. If there is a strong physical base, then that lesson time and ice time can be used much more effectively and skaters will experience more success in the sport and hopefully stay in the sport longer.

I proposed that skaters who are more physically fit acquire more difficult skills such as jumps and basic skating much quicker than other skaters with less of a physical foundation. It is been my experience that skaters who skate less but play other sports and have a great physical foundation obtain several technical skills much quicker that skaters who have great volumes of figure skating training but lack the same physical foundation. Currently this is only a personal observation. It is my wish to provide an evidence-based approach for creating better training programs for figure skaters. Traditional training methods consist of one hour freeskate practices including a 15 minute private lesson. Traditional training in this manner lacks the development of the physical fitness component that is critical to achieving technical skills in figure skating. In continuing to coach sessions and plan programs in this manner, figure skaters are set up for failure by not developing the physical abilities required to perform these technical skills.

1.3.2 Addressing Gaps in Current Literature

There have been over 30 studies in the past 50 years that have examined physical and skill related fitness levels to the success or biomechanics of certain elements in figure skating. However, almost all of these studies have investigated skaters of high proficiency near the elite level(Albert & Miller, 1996; Aleshinsky, Podolsky, McQueen, Smith, & Van Handel, 1994; Bower et al., 2010; Brock & Striowski, 1986; Comuk & Erden, 2012; Dubravcic-Simunjak et al., 2003; D. King et al., 1994; King, Smith, Higginson, Muncasy, & Scheirman, 2004; King, 2005; Kjaer & Larsson, 1992; Pies, Neeves, & Richards, 1998; Podolsky, Kaufman, Cahalan, Aleshinsky, & Chao, 1990; Ross, Brown, Yu, & Faulkner, 1977; Sands, Kimmel, McNeal, Murray, & Stone, 2012; Smith & Ludington, 1989; Tornese, Botta, Mattei, & Alpini, 2011). There have been many other studies on figure skaters to investigate their cognitive abilities such as memory (Deakin & Allard, 1991), self modelling (Law* & Ste-Marie, 2005) and the effects of different types of instruction (Haguenauer, Fargier, & Legreneur, 2005). Studies involving the youngest skaters were only focused on boned density and age of menarche (Moison, Meyer, & Gingras, 1991; Monsma, Malina, & Feltz, 2006; Monsma, 2008; Oleson, Busconi, & Baran, 2002; Prelack, Dwyer, Ziegler, & Kehayias, 2012; Vadocz, Siegel, & Malina, 2002). Figure 1 shows the mean ages of figure skaters investigated in various studies within the past 50 years and the ages of skaters to be investigated in the proposed investigation. Skaters of ages 6-11 years of age have not been investigated in figure skating (Figure 1) in any capacity, even though this is a crucial time for development in such an early specialization sport.

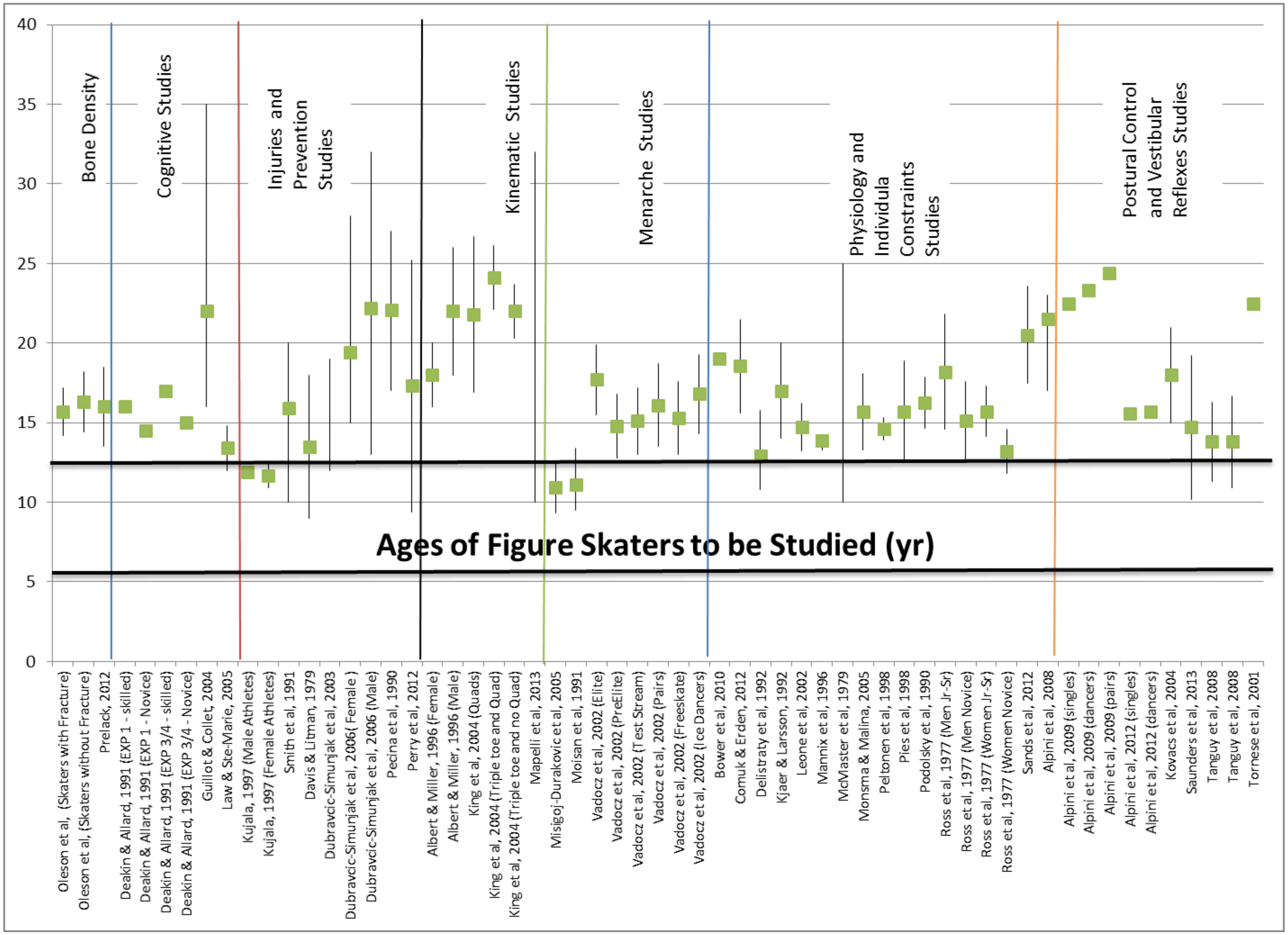


Figure 1: Graph of Ages of Skaters Previously Investigated in Literature

1.4 Thesis Investigation

The purpose of this study is to investigate the relationship between physical fitness and the on-ice performance of developmental figure skaters. Skaters from the Learn to Train Stage of the Skate Canada LTAD categories of STAR 2, STAR 3, STAR 4 and STAR 5 are considered developmental figure skaters who must acquire mandatory skills for continuation in the sport. Eleven components of health related and skill related physical fitness will be tested using standardized protocols. Health related physical fitness tests include muscular strength tests (Grip Strength, Vertical Jump, Plank Test), muscular endurance tests (Timed Tuck Jumps, One Minute Sit-Ups and One Minute Modified Push-Ups), and flexibility tests (Sit and Reach and Standing Spiral). Skill related fitness tests will include agility (Hexagon Test and T-Test), and balance (Stork Stand). On ice performance will be ascertained using a one lap speed test, and an assessment of key figure skating elements including the back spin, sit spin, camel spin and the axel jump which are mandatory skills that need to be acquired by the end of this stage of development. Jump assessments will be conducted by a panel of three qualified judges. Off ice tests and measurements will be conducted by qualified certified coaches or personnel.

The types of training required to produce a good figure skater are currently left to the coaches' judgment and decisions are made based on very little scientific evidence (Niinimaa, 1982). It would be beneficial to provide coaches of developmental skaters with some physical fitness reference information as a tool for developing skills. This study may identify barriers such as constraints to skill development milestones in figure skating at the Learn to Train stage of the LTAD. By identifying these barriers such as strength or agility, a better understanding of athlete development may be achieved. Examining the relationship between physical and skill related fitness to on-ice performance may provide evidence to guide future program planning and generate guidelines for training programs.

1.5 Research Questions and Hypothesis

Skill-related and health-related components of physical fitness may act as constraints on the acquisition of various figure skating skills (e.g., jumps, spins, and basic skating). The main objective of the study will be to investigate and examine the relationship between the physical fitness to on-ice performance of developmental figure skaters. Significant skills in figure skating include the axel jump, back spin, camel spin and sit spin.

Main Objective:

To determine if any physical fitness capability is a constraint on the acquisition of the axel jump in figure skating.

Alternative Research Questions:

To determine if there is a relationship between physical fitness capabilities and the performance of on-ice skills such as speed, and the overall performance of the axel jump, the sit spin, back spin and camel spin.

To determine if there are correlations within the on-ice performance of figure skating skills.

CHAPTER TWO FOUNDATIONAL CONCEPTS UNDERLYING THE RESEARCH

2.1 Introduction

Figure skating is acknowledged as an early specialization sport, which has many implications for training. For figure skating and other early specialization sports, there are copious opinions on the risks associated with early specialization that contrast with opinions on benefits but there is little research to support any of these theories and it is mostly speculation. Skate Canada has outlined training needs for its athletes based on its version of the Long Term Athlete Development Model. The purpose of the LTAD is to ensure that child participants develop proper skills and set a physical foundation for future health and participation in sport (Skate Canada, 2010). Through this model, acquisition of skills at different stages of development are illustrated. However, the model is ambiguous in terms of outlining anything concrete as a guideline for development. It outlines physical abilities that need to be trained but does not give any quantifiable indication of what levels may be required. A lack of health-related or skill-related fitness in a figure skater may hinder the acquisition of certain difficult skills such as the axel jump. These hindrances can be viewed as constraints according to the model of constraints proposed by Karl Newell (Haywood & Gretchell, 2001).

2.2 Early Specialization

Specialization in sport is a term used to describe an athlete who has made the decision to train and compete year round almost exclusively in a single sport (Balyi et al., 2014; Kaleth & Mikesky, 2010). Contrary to specialization, recreational sport participation occurs only for the fun or love of the sport while reaping the health benefits of physical activity (Balyi, Way, &

Higgs, 2013) and possibly participating in many sports. Early specialization sports are defined as sports in which early sport-specific training (by ages 5 to 7) is necessary to acquire future excellence (Balyi et al., 2013). For these sports, complex movement and sport skills need to be attained before the onset of the adolescent growth spurt, which is approximately 12 years of age for females and 14 years of age for males (Balyi et al., 2013). Specialization is necessary to be successful at an elite or world class level in all sports, but the age at which an athlete begins to specialize varies depending on the sport. For example, in some sports early specialization is considered a necessity to develop complex skill patterns before reaching a certain level of maturity, after which the acquisition of certain skills becomes far more difficult. Common early specialization sports include artistic and acrobatic sports such as gymnastics, diving, and figure skating (Côté & Gilbert, 2009; Foley & Bird, 2013; Gould, 2010; E. V. Monsma et al., 2006; E. V. Monsma, 2008; Skate Canada, 2010; Vadocz et al., 2002).

In contrast, the literature is lacking to even define what late specialization is in comparison. What is known is that an athlete with prior and substantial athletic abilities can become successful in a late specialization sport if they begin around the ages of 16-20 years (Baker, Cobley, & Fraser-Thomas, 2009). Late specialization provides the opportunity for individuals to become very good, especially after their bodies have matured and they have developed increased strength or stamina. Late specialization sports rely on skills and body physiques that can be developed after puberty while early specialization sports require the acquisition of skills that are best developed before puberty (Balyi et al., 2014). Table 1 refers to qualities of early and late specialization sports by Balyi et al., (2014). While there is a multitude of literature of opinions, explanations and theories on early versus late specialization, there is little scientific evidence to support any of these theories.

Early Specialization	Late Specialization • Early Engagement
• **Acrobatic (gymnastics, diving, figure skating)**	• Kinesthetic (alpine ski, freestyle ski, luge, cross country ski)
• **Highly kinesthetic (important to engage in activities that involve snow, water or a horse early on e.g. snowboard, swimming, synchro, equine)**	• Team (basketball, ice hockey, baseball, rugby, soccer, water polo, field hockey)
• **Demanding and complex motor skill requirement**	• Visual (tennis, badminton, squash, fencing)
	• Standard (typical timing of specialization – majority of sports fit into this category)
	• Very Late Specialization (cycling, wakeboard)
	• Very Late Specialization; Transfer – when the skills developed in one sport allow an athlete to smoothly transition into another sport (rowing, triathlon, volleyball – beach and indoor, bobsleigh)

Table 1: Groupings of Sport within Early and Late Specialization - Adapted from Balyi 2014

Sports that require early specialization have certain characteristics. Early specialization sports require a high degree of kinesthetic awareness regarding elements or objects other than the athlete such as ice (skating sports), snow (snow sports), water (swimming sports) or animals (equine) (Balyi et al., 2014). It is this awareness that takes many hours and years to train. Gymnastics, diving, and figure skating are among some of the sports that have an additional element of being very acrobatic (Balyi et al., 2014; Côté & Gilbert, 2009; Foley & Bird, 2013; Gould, 2010). Success in these sports favour late maturing athletes (reaching puberty at later ages) who have smaller, leaner body types, which are more advantageous for acquiring the complex acrobatic skills (Balyi et al., 2014; Côté & Gilbert, 2009; Foley & Bird, 2013; Gould, 2010). In addition, other characteristics of early specialization sports include routines (i.e., closed motor skills), relatively simple decision making, and highly precise technique (Balyi et al., 2013).

According to Baker and colleagues, early specialization includes 4 parameters: early start age in the sport; early involvement in one sport (as opposed to many different sports), early involvement in focused, high intensity training; and early involvement in competitive sport (Baker et al., 2009). These parameters are a requirement for success in the early specialization sport but can have detrimental effects on athletes involved in late specialization sports (Baker et al., 2009; Balyi et al., 2013, 2014; Gould, 2010; Kaleth & Mikesky, 2010; Malina, 2010).

It has been suggested that a minimum of 10 years of practice 10,000 hours is needed to reach a level of expertise in any field including sport domains (Balyi et al., 2014; Burgess & Naughton, 2010; Ericsson, 1996; Gonçalves C, Rama L, & Figueiredo, 2012; Gould, 2010; Skate Canada, 2010). However, this rule has been misconstrued to mean that anyone can reach international performance levels in 10 years whereas the real truth is that even the most talented individuals required approximately 10 years of intense practice to reach expertise while many others require much more (Ericsson, 1996). The reality is that very little of the sport participants ever make it to the elite levels and many of the elite did not specify early into their sport but rather had a very diversified specialization in sport at an early age (Malina, 2010). Gould (2010) states that in order to develop talent, athletes must specialize (Gould, 2010) at some point. Achieving excellence takes years of practice and in sports where the top international competitors are teenagers, using the 10 year rule as a guideline means specialization must occur a decade or so before. In this case, for sports such as figure skating, early specialization as a child is required, in part, because the top international athletes are still children themselves. Table 2 refers to the average ages of athletes participating in the 2012 London Olympic Games by sport. While the average age of the athletes was 26, rhythmic and artistic gymnastics as well as diving had the lowest average ages of athletes (Guardian News and Media Limited, 2014) of 19, 20 and 22 respectively. It could be speculated that specialization for these athletes occurred around the ages of 8-12 years of age.

Sport	Age	Height, cm	Weight, kg
OVERALL AVERAGE	26.1	176.9	72.8
Archery	26.1	173.7	71.9
Athletics	26.2	176.0	69.2
Athletics, Triathlon	30.0	173.0	60.0
Badminton	26.2	173.6	66.8
Basketball	27.2	192.1	87.0
Beach Volleyball	29.2	187.0	80.0
Boxing	24.0	175.0	
Canoe Slalom	26.8	175.3	70.2
Canoe Sprint	26.2	179.4	78.2
Cycling - BMX	23.5	176.1	77.6
Cycling - BMX, Cycling - Track	23.0	170.0	79.0
Cycling - Mountain Bike	27.9	173.6	62.4
Cycling - Mountain Bike, Cycling - Road	33.0	173.5	60.5
Cycling - Mountain Bike, Cycling - Road, Cycling - Track	26.7	170.3	57.0
Cycling - Mountain Bike, Cycling - Track	24.3	183.0	80.7
Cycling - Road	28.3	176.7	66.8
Cycling - Road, Cycling - Track	29.4	173.6	66.1
Cycling - Track	25.2	175.7	72.3
Diving	22.9	165.5	59.8
Equestrian	37.9	174.4	67.2
Fencing	26.3	176.7	69.6
Football	23.3	174.1	68.7
Gymnastics - Artistic	22.1	161.1	
Gymnastics - Rhythmic	19.5	170.1	
Handball	28.0	183.8	82.5
Hockey	26.0	173.2	69.0
Judo	25.9	173.5	76.7
Modern Pentathlon	25.4	175.4	65.9
Rowing	27.2	185.6	80.9
Sailing	28.3	177.9	74.2
Shooting	31.4	172.1	72.9
Swimming	22.4	179.5	71.6
Synchronised Swimming	22.8	168.6	
Table Tennis	27.6	172.1	66.2
Taekwondo	24.1	176.3	
Tennis	27.1	180.1	72.9
Trampoline	25.6	166.3	
Triathlon	27.9	174.0	61.2
Volleyball	26.6	189.7	79.9
Water Polo	26.8	185.6	85.4
Weightlifting	24.6	166.6	77.5
Wrestling	26.0	172.5	74.6

Table 2: Average Age of Athletes in London Olympic Games by Sport - Adapted from The Guardian News and Media

Research has also identified a number of negative consequences associated with early specialization: over training, burnout, and injuries (Baker et al., 2009; Balyi et al., 2014; Burgess & Naughton, 2010; Gould, 2010; Kaleth & Mikesky, 2010; Lipetz & Kruse, 2000; Malina, 2010; Skate Canada, 2010). It is postulated that early sport specialization in late specialization sports can have many detriments on childhood. It is also suggested that children who specialize early are more susceptible to social isolation, wherein they may not have the time to develop friendships and social connections (Gould, 2010; Malina, 2010). In terms of psychological development, children who diversify during their early years of sport tend to integrate sport better into their family and community life; while those who specialize early are shown to experience greater levels of stress and exhaustion (Gould, 2010). Besides the social isolation, loss of motivation and burnout, there is also increased pressure and stress due to over competing (Gould, 2010). This adds to an increase in the risk of overuse injuries due the high volume of repetitive movements (Kaleth & Mikesky, 2010). However, sport related injury rates are unreliable due the individual differences in physical maturations, as well as differences in training volumes and training methods associated with early sport specialization (Kaleth & Mikesky, 2010).

Instead of early specialization, many sport scientists instead advocate for an early diversified pathway towards expertise (Baker et al., 2009; Burgess & Naughton, 2010; Gould, 2010). Sport diversification refers to an individual's participation in a variety of different sports during one's youth, also referred to as the 'sampling years' (Baker et al., 2009; Burgess & Naughton, 2010). The sampling years (typically between the age of 6 and 12 years) is considered a sensitive period of development, wherein a child should be provided the opportunity to experience a variety of sports (Burgess & Naughton, 2010). Such an approach is suggested to increase one's breadth of foundational skills (Balyi et al., 2013). It is suggested that diversification is most valuable when a child is involved in activities that require the learning of new skills and improvement in performance (Baker et al., 2009). If an individual specializes early in a particular sport and is not provided an opportunity for diversification, it is postulated that future participation in other sports will be limited (Baker et al., 2009; Balyi et al., 2013; Gould, 2010). In contrast, early diversification is purported to increase overall motor proficiency, thereby better facilitating lifelong sport participation (Baker et al., 2009). In general, early diversification actually provides the opportunity for an individual to gain a wide variety of athletic abilities by a general specialize in sport, versus specialization which limits the individual's expertise to one single sport. In support of diversification, it could be argued that diversification increases the opportunity to transfer certain sport skills across sporting domains, including cognitive skills and physiological conditioning (Baker et al., 2009) .

Early specialization sports such as figure skating and gymnastics that require a high level of athletic abilities and a diversification of skills to be successful (Fortin & Roberts, 2003; McMaster et al., 1979). If trained properly in these sports, a diversified athletic background can be obtained. Many parents enroll their children in gymnastics at early age in the belief that they will gain an advantage with the physical awareness of their bodies. As well, many parents involved in skating related sports, enroll their children in figure skating to develop a good base of skating skills that can give them an advantage in hockey or other skating sports.

A figure skater must learn and master skating in multiple directions including forwards, backwards, clockwise and counter clockwise, over 64 different one foot turns, two foot turns, 6 different listed jumps with multiple rotations, many unlisted jumps for choreography, a wide variety of spin positions, field movements, plus a plethora of moves related to choreography and connecting steps. It can be argued that in order to be successful in the sport, a skater must master a wide diversification of skills.

To date, research examining the effects of early sport specialization is rather limited (Baker et al., 2009; Gould, 2010). Moreover, arguments regarding specialization versus diversification remain unresolved (see Baker et al, 2009). For example, there is scant evidence supporting the argument that early specialization effects growth and maturation rates; rather, late-maturing athletes with smaller physiques tend to self-select into these sports (Kaleth & Mikesky, 2010). In addition, there is little evidence to suggest that early specialization is the cause of overuse injuries (Baker et al., 2009). In general, figure skating is a sport that is considered to have a low injury rate (Sandra Dubravcic-Simunjak et al., 2003).

Though little research has been done, there are some suggested benefits of early specialization. While there is little research on the effects of early sport specialization, there may be a physiological advantage to participating in particular early specialization sports at early age (Kaleth & Mikesky, 2010) such as developing greater relative strength and flexibility. Other benefits of early specialization in sport include access to better coaching and instruction and extra hours of practice (Gould, 2010) . These possible benefits of early specialization may be sport specific with figure skating having a clear performance benefit (Mattson & Richards, 2010) due to the need of high level of physical fitness required that lie beneath the technical skills.

2.2.1 Conclusion

There is limited research examining the effect of early specialization in sport (Baker et al., 2009; Gould, 2010), especially in those sports where there is an emphasis on specializing early (e.g., figure skating). Research in the area is difficult due to a variety of factors such as individual differences in maturation rates, sport requirements, training techniques, and ethical considerations (Kaleth & Mikesky, 2010). As figure skating is an early specialization sport, it is hoped that this study might fill in some of the gaps around early specialization and the possible benefits in terms of physical and health related fitness levels of children. This study proposes to include participants who are of the same levels but may be specializing in skating or only participating in skating and sampling other sports and so it may yield some insight into early specialization versus early diversification. By testing certain health related and skill related physical fitness parameters, and collecting information from the participants, including training hours, and other sport participation, some knowledge surrounding the concept of early sport participation and sampling might be gained.

2.3 Long Term Athlete Development

Previously, the Canadian approach to progression into high performance sport was based on a pyramid system that outlined a pathway to the top that eliminated athletes along the way who did not meet the standards for progression into the next level (Balyi et al., 2013). From this perspective, sport and recreation were considered separately. In 1995, a more concerted effort in Canada was put towards developing a long-term athlete development program with the intention of improving sport programming for all participants. Long-Term

Athlete Development (LTAD), Canadian Sport for Life, and No Accidental Champions became initiatives of Sport Canada to focus on the general framework of athlete development with special reference to growth, maturation, and development (Sport Canada, 2009). Federal, provincial, and territorial Ministers of Sport endorsed the Canadian Sport for Life concept in 2004 and set out to develop an athlete pathway that outlined the distinct phases development (physical, mental, cognitive, and emotional) based on the maturation of an individual rather than their chronological age (Sport Canada, 2009). The intention of the LTAD is to improve participant development as it relates to coaching, training, equipment, and the introduction of appropriate amounts of competition for age (Sport Canada, 2009). In Canada, policy makers have pressured sport organizations into accepting the approach as a practical pathway for all sports. These LTAD pathway documents claim to utilise empirical coaching observations and experiences, coaching science, as well as human growth, development, and maturation principles as a foundation (Balyi et al., 2013). Over the last several years, Skate Canada has made many changes to the sport on the basis of its new LTAD model especially in the Learn To Train Stage of developing skaters. The Provincial Sport Organization for figure skating in British Columbia , BC/YK Section, has been piloting a new series of tests and competition levels designed at changing the nature of training and coaching at this level.

2.3.1 The Long Term Athlete Development Pathway

The Long Term Athlete Developmental Pathway has been outlined in stages that may vary for individual sports. Figure 2, refers to the Long Term Athlete Pathway for Sport within the Sport Canada domain. The first three stages (Active Start, FUNdamentals and Learn to Train), reflect the time when children should be acquiring their basic fundamental movement skills and physical literacy to support and set a baseline for progression into the next stages. It should also foster a love for sport based on participation. The next stages are built around specific sport skill acquisition, aspiring towards excellence, and proficiency within the sport. The last stage is focussed on encouraging a life-long passion for participation in sport and physical activity.

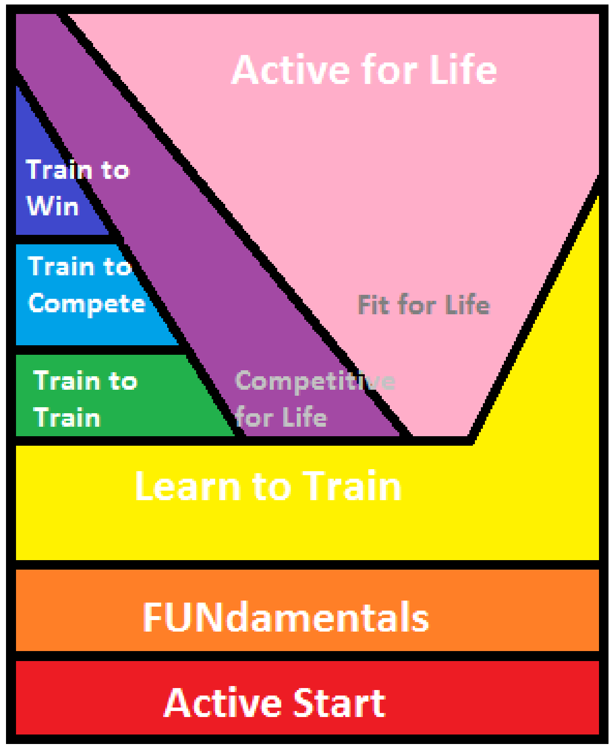


Figure 2 **The phases of long-term athlete development as proposed in the Canadian Sport for Life Long-term Athlete Development Model (Adapted from Balyi et al. (2014)).**

In general, long-term athlete development models focus on how participants and athletes are trained to develop skills while other components include competition structure, coach training and development, officials' training and development, sport leadership, sport facilities, equipment, technology, sport medicine, and sport sciences. It also recognizes the important supporting roles of parents/guardians, volunteers, officials, administrators, sponsors, sport medicine practitioners, and sport scientists (Skate Canada, 2010). According to Skate Canada, the basis of athlete development is the concept of physical literacy which is defined as competency in fundamental movement skills (run, jump, throw, swim) as well as motor skills (ABC's: agility, balance, coordination, speed) and fundamental sport skills (preferably before the age of 12) (Balyi et al., 2014; Skate Canada, 2010). If this is the case, then skaters in the learn to Train Stage of figure skating should be proficient in agility, balance, speed and other fundamental sport skills outlined in this research proposal.

2.3.2 Skate Canada's LTAD

Skate Canada's Long-term Athlete Development Model is divided into a series of stages. Table 3 outlines the stages of development and their suggested chronological ages within figure skating. Through this model, the different stages of development are illustrated. For the Skate Canada LTAD, the Learn to Train stage is identified as the developmental stage in which the physiological factors as outlined as shown in Table 4 must be introduced and developed through specific programming and coaching and in accordance with age and gender.

Stages of Development	Suggested Chronological Ages
Learn to Skate (Active Start/FUNdamentals)	age: females 3-8; males 3-9
Learn to Train	age: females 7-11; males 8-12
Learn to Compete	age: females 9-13; males 10-14
Train to Compete	age: females 10-16; males 11-17
Learn/Live to Win	age: female 13-19; male 14-21
Active for Life	any age

Table 3 Skate Canada Long Term Athlete Development Stages adapted form Skate Canada

Physiological Factors	Estimated Ages
Skills	("golden age": 8-12)
Speed	(female: 6-8; male: 7-9)
Suppleness (Flexibility)	(female/male: 6-10)
Stamina	(at the onset of PHV-peak height velocity)

Table 4: Physiological Factors that need to be developed for the Learn to Train Stage Adapted from Skate Canada

The purpose of the Skate Canada LTAD is to ensure that skaters develop the proper skills and set a physical foundation for future participation in sport. Table 4 outlines the physiological factors that need to be developed for the Learn to Train Stage in figure skating. The sport specific skills that should be mastered by the exit of the Learn to Train Stage are outlined in Table 5. The Skate Canada Long Term Athlete Development document outlines the general skills and training in Table 6. However there is much ambiguity in all these tables as they do make any parallels with any of the Skate Canada programs or levels of competition. This is a common problem in most sport LTAD models, wherein the characteristics of development at each stage do not include elements that are quantifiable for the coach (Cote, Murphy-Mills, & Abernethy, 2012).

The stage of focus in the proposed research is the ‘learning to train’ stage of the long-term athlete development model for figure skating (see Figure 1, Table 3). While Skate Canada states that females and males in this stage need to increase the development of such factors as speed and suppleness, guidelines provide no additional information as to what coaches should be targeting as appropriate levels. As another example, it is also stated that skaters should begin to demonstrate appropriate levels of stamina (Skate Canada, 2010). The questions remains as to what an appropriate level of stamina is.

Age :	Female (7-11) and Males (8-12)
Motor Skills	Continued development of balance, agility and coordinate demonstrated by: • Developing awareness of the relationship between speed and lean • Kinesthetic awareness: repeating shapes and pathways: following movement through space; recognizing steps, ad being able to describe them, movement combinations, perception of movement in self, opposition of legs, arms and torso • Use of the blade and interface with the ice – changing the balance point (gliding, rocking, sliding), multiple turning/twisting and learning tasks, use of the toe pick, production and manipulation of force • Understanding the movement of joints – backbone, hip joint, head, legs and arms, rotational movement of the spine line. • Skater's perception of their own body rhythm
Technical	**Edges** • Able to perform well controlled strong, fast edges including a back change of edge • Lean, depth of curve, and control demonstrated on both fee and all edges **Turns** • Able to perform step sequences with simple, clean edges and turns • Demonstration of multiple turns executed with flow in both direction and on both feet • Multiple turns, brackets, counters, Choctaws and loops are introduced and developed • Skaters should begin learning the rocker mechanism **Stroking** • Demonstration of a very good cross cut technique including push with the blade, acceleration and maintenance of speed and flow and body carriage • Able to vary the timing of crosscuts with ease in both directions, forwards and backwards **Jumps** • Able to perform single jumps with speed and control • Able to execute single axels and two or more clean double jumps • Developing double/double combination • Some understanding of how doubles will become triples • Consistent and correct air and landing positions

	Spins • All forward and backward spinning positions, and changes of positions well executed • Able to perform combination spins that include all three basic positions • Demonstration of some basic position variations with minimal to no loss of speed **Field Moves** • Ability to perform both supported and unsupported spiral positions as well as other field moves (ie., spread eagle, Ina Bauer, pivots, etc) • Demonstrated ability to maintain speed and flow in basic field movement positions • Learning to perform simple field moves in transitions
Artistic	• Able to demonstrate an understanding of beat, temp, dynamics and simple rhythm through movement • Introduce various musical themes and instill an appreciation of the differences • Introduce use of the full body and different levels of movement (is. High, medium, low) • Participation in ballet and other types of dance training in addition to other off-ice sessions

Table 5: Sport Specific Skills needed to be mastered by Exit of Learn to Train Stage adapted by Skate Canada

AGE	FEMALE (7-11) AND MALES (8-12)
PHYSIOLOGICAL	• Increased development of motor skills, speed and suppleness • Ability to perform basic strength training movements using own body weight, medicine balls and stability balls • Beginning to demonstrate appropriate levels of stamina

PSYCHOLOGICAL	• Acquired basic knowledge of fundamental mental skills (ie. What they are and what their function is) including:
	    • Focus and anxiety management strategies
	    • Goal setting
	    • Mental preparation for practice, testing and competition
	    • Positive self-awareness/self-concept

SOCIAL	• Increased knowledge of the rules and ethics of sport • Some ability to act as both leader and follower and demonstrated ability to cooperate with others • Ability to take risks and/or meet challenges presented. • Learning to measure success through self-evaluation • Demonstrated understanding that education remains the most important priority

Table 6: General Skills for the Learn to Train Stage of Skate Canada's LTAD Adapted from Skate Canada’s LTAD Model

Table 7 outlines the training needs and training times suggested by Skate Canada for this stage of development. It leaves a wide range of training hours to be interpreted by parents, athletes, and their coaches as to how much training may be required to reach a certain level of proficiency. From this table, the number of hours of training for entry into this stage for a maximum are five times greater than suggested minimum hours as shown in Figure 3. As figure skating is an early specialization sport requiring many hours of practice to get a feel for the ice, training age in terms of hours trained may be a more reliable predictor of skill and entry and exit points to stages rather than chronological ages.

Entry	**Session Length**	• **45-60 minutes on-ice, with 15 minute off-ice warm-up prior** • **Maximum one session/day**
	Days/Week	• 2-4 days/week
	Weeks/Year	• Minimum: 20 weeks/year • Ideal: 30 - 40 weeks per year
Exit	**Session Length**	• **45-60 minutes on-ice, with 15 minute off-ice warm-up prior** • **1-2 sessions/day**
	Days/Week	• 4-5 days/week
	Weeks/Year	• Minimum: 40 weeks/year • Ideal: 44 weeks per year

Table 7: Training hours and sessions for the Learn to Train Stage of Skate Canada's LTAD Adapted from Skate Canada LTAD model

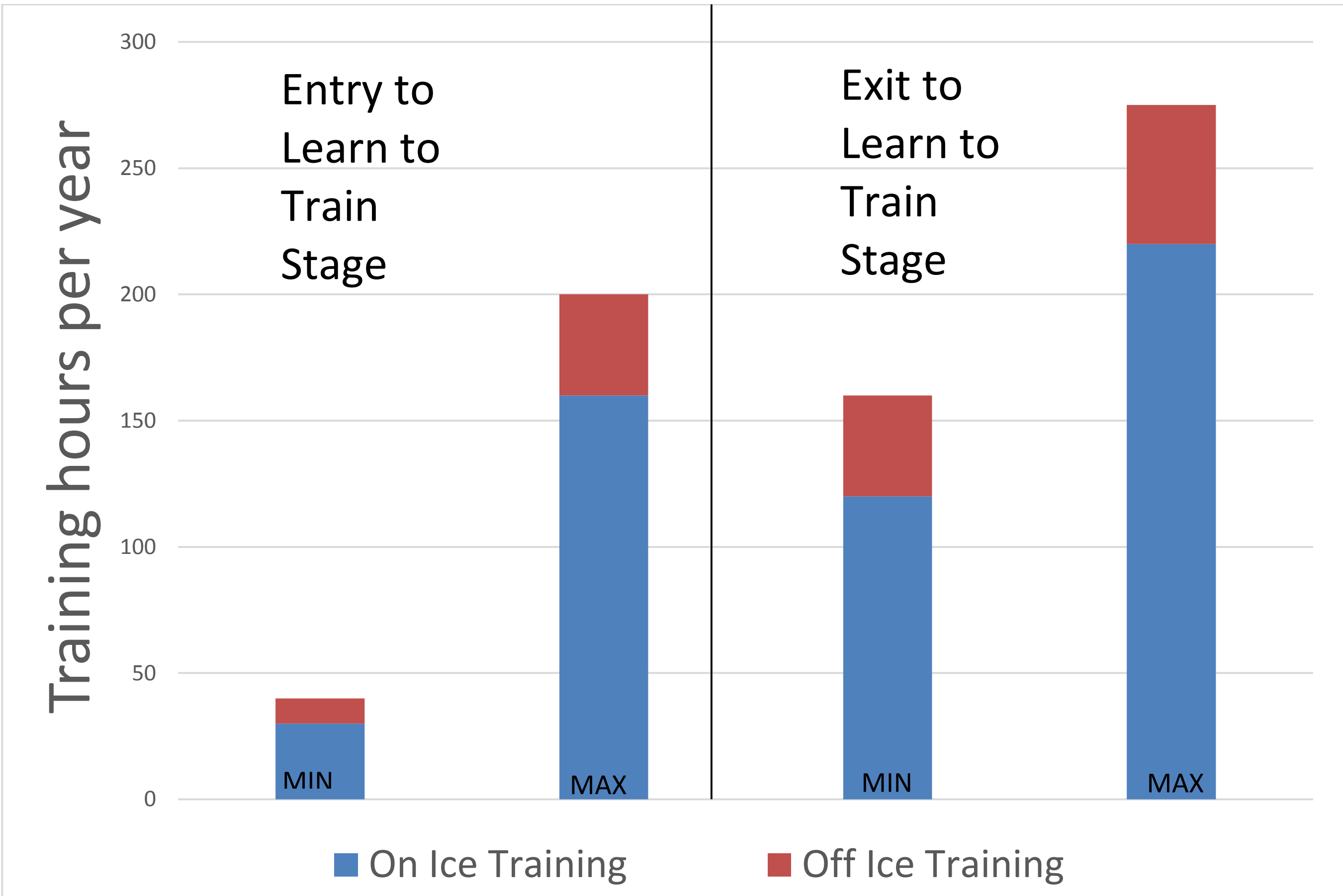


Figure 3: Graph representing the number of training hours suggested by Skate Canada for minimums and maximums for the Learn to Train Stage

Skate Canada has outlined training needs for its athletes based on its version of the Long Term Athlete Development Model. Appendix A contains The Learn to Train Stage portion of Skate Canada's Long Term Athlete Development Model. The purpose of the Skate Canada LTAD is to ensure that skaters develop the proper skills and set a physical foundation for future participation in sport. Through this model, the different stages of development are illustrated. However, the model is very ambiguous in terms of outlining anything concrete as a guideline for development, especially in terms of skills or physical development. It outlines physical abilities that need to be trained but does not give any quantifiable indication of what levels may be required.

Because the sport of figure skating is more dependent on training age rather than chronological age, setting any concrete standards for age and level is very difficult. In trying to be inclusive, there lacks any useful information for coaches working with developing skaters. Skate Canada positions that training the right skills at the correct stage of development is key to the success of all athletes, from beginners to elite athletes (Skate Canada, 2010).

In summary, though the LTAD provides a framework for developing athletes, it is not very useful as a guideline for coaches, parents, or athletes who want to know where they are located in the model and what is required for them to reach their goals. There are no benchmarks for development in terms of skills or physical abilities. There are no guidelines for training and how it should be focussed to train these skills and physical abilities and how it is related to training age versus chronological age. The Skate Canada LTAD model is useful as a curriculum guide but not as a developmental tool as it lacks the connections to figure skating contexts of skating levels.

This study investigated some of the key skills outline above such as the axel, the sit spin and camel spins as basic spin position requirements, and the backspin as both a basic spin position and a key rotational jumping aspect as referred to in Table 5. An on-ice speed assessment ascertained the proficiency of the skater by combining the aspects of edge control and balance as it relates to developing and maintaining speed and flow over the ice. As well, aspects of physiological development were assessed to determine the relationship of the skating elements to the physical development of the skater as mentioned in Table 6. This research attempts close some of the gaps between the parallel aspects of sport; skill development and physical capabilities.

2.4 Constraints: A Model for Examining Skill Acquisition

A lack in physical fitness may be defined as a constraint on the acquisition of certain technical skills in figure skating. It is important to understand the framework for movement and skill acquisition as acknowledged in the literature. One contemporary approach to understanding the emergence of movement across the life span is derived from the ecological perspective and is referred to as Newell's Model of Constraints (1986). Newell's model suggests that movement is based on a dynamic interaction between three factors: the individual, the environment, and the task to be performed. Whenever one of these factors change, the movement dynamically adjusts and changes (Haywood & Gretchell, 2001). Within the model, these three factors are also referred to as movement *constraints* and influence the movement that emerges. That is, a constraint can limit or discourage the emergence of a certain movement, while permitting or encouraging the emergence of another movement. The constraints led approach to motor learning is a pedagogical approach based on learner as a non-linear dynamical system and is promoted as a framework for understand how children (and adults) acquire movement skills for exercise and sport (Davids, 2010). Figure 4 illustrates Newell's Model of Constraints and how task, environmental, and individual constraints are related. Task and environmental constraints are located outside the body. A task constraint refers to the goals, equipment or rules of the game (Haywood & Gretchell, 2001). The fact that one and a half rotations need to be successfully rotated and landed on one foot to get credit for an axel jump would be a task constraint in figure skating. An environmental constraint is indicated as a property of the world around us (Haywood & Gretchell, 2001). In figure skating, the most significant environmental constraint is gravity. The arrow in Figure 4 highlights how adaptations in physical constraints can be influenced towards to goal of a task and are important in the acquisition of a skill. For example, increased strength or agility will affect the ability of the skater to achieve the goal of successfully landing an axel. More specifically, individual constraints refer to an individual's physical and mental characteristics and may be further classified as structural or functional. A structural constraint is defined as within the structure of the individual such as height or weight (Haywood & Gretchell, 2001). A functional constraint is something that is related to the individual's behavior such as motivation or concentration (Haywood & Gretchell, 2001).

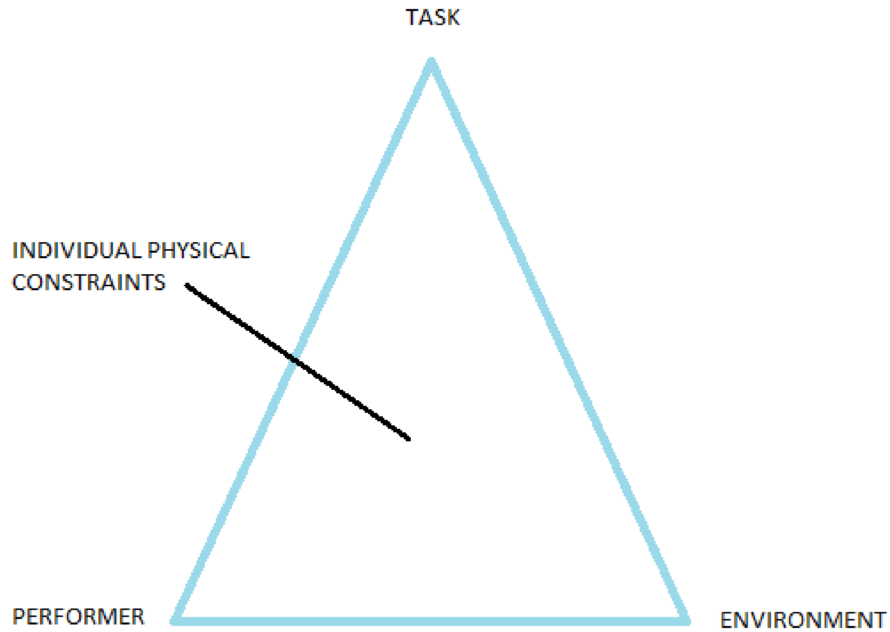


Figure 4: Schematic based on Newell's Model of Constraints (1986) with the addition of role of physical fitness as individual constraints. Adapted from Haywood & Gretchell, 2001.

For children, their physical fitness level, technical abilities, or psychological factors may affect their capability to learn skills (Renshaw, Chow, Davids, & Hammond, 2010) . Physical abilities such as agility, coordination, strength, and flexibility are hereditarily central features that affect movement performance (Haibach, Reid, & Collier, 2011) .   Whereas skills are learned, abilities are a product of both learning and genetics (Haibach et al., 2011). Skills can be referred to as a level of aptitude for a specific motor task (Haibach et al., 2011). An individual's traits that affect the capability to become skillful when learning a new motor task would be referred to as abilities (Haibach, Reid, & Collier, 2011). A figure skater performing the triple axel requires physical abilities such as explosive strength, dynamic flexibility, and coordination of many joints and limbs (Haibach et al., 2011). An ability or disability may constrain, but not prevent the acquisition of a task such as swimming, jumping a hurdle, or landing a fully rotated axel in figure skating (Haywood & Gretchell, 2001). For example, a lack of agility in figure skating may affect one's ability to successfully rotate an axel because they lack the ability to get into the rotational position quickly or tight enough. However, if the skater has enough strength to compensate for this by achieving greater height and time in the air, then the skater may be able to perform the jump successfully after all.

For a coach, it is important to know if an athlete's movement is being influenced by a structural or functional constraint.   Coaches in figure skating spend most of their time on error detection and corrections of skills and technique. For the acquisition of an axel, common functional constraints restricting the emergence of the skill may be a lack of motivation or a fear of falling. In this case, the error detection method isn't as useful because the skater's constraint is functional. In contrast, not possessing adequate strength or flexibility are examples of structural constraints that may restrict acquisition of the skill. If the coach can ensure that there is adequate physical fitness such as agility or muscular strength required for the skill, then the error detection and correction method can focus more on the efficiency of the technique.   Coaches need to understand the nature of the constraints that each individual athlete needs to satisfy during sport performance (Araujuo, Davids, Bennet, Button, & Chapman, 2004)

In conclusion, most of the literature surrounding constraints and their approach to learning have been on manipulating the task or environmental constraints in order to increase learning. Literature on the effects of manipulating constraints surrounding the performer are extremely limited. This study investigated parameters of health-related and skill-related fitness as individual physical constraints on performance of on-ice skills in figure skating in relation to the performer.

2.4.1 The Emergence of Required Elements in Figure Skating

Every skating program has required elements that need to be performed in competition at every level of skating. Figure skating competition categories are first determined by the skaters' level, and then by age, only when ranking of the skaters is involved. Table 8 outlines the new STAR categories for Skate Canada's Long Term Athlete Development implementation. There is always a forward entry jump requirement based on the axel. The STAR 2 skaters are still working on all their single jumps and are required to perform the waltz jump (one half rotation). Beginning at STAR 3, skaters are allowed to perform an axel jump if they can do one. Most, but not all, skaters at the STAR 5 level can successfully perform an axel. This requirement of the axel type jump becomes a double axel jump for female skaters at the Novice Level and higher of competition.

Competitive Category	STAR 2	STAR 3	STAR 4	STAR 5
Type of Assessment	Compulsory Assessment Program	Free Skating Program – Assessment Only	Free Skating Program – Assessment and Ranking	Free Skating Program – Ranking with Report
Required Elements in Program	• Waltz Jump • Back Upright Spin • Forward Sit Spin or Camel Spin	• One Axel type jump (Waltz jump or single Axel) • Back Upright Spin • One Combination Spin that must include one camel and one sit position	• One Axel type jump (Waltz jump or single Axel) • Back Upright Spin • One Combination Spin that must include one camel and one sit position	• One Axel type jump (Waltz jump or single Axel) • One Combination Spin that must include all 3 basic positions (sit, camel, upright) • Additional Camel Spin or Sit Spin
Restrictions	*All elements predetermined	No double jumps permitted	No double jumps permitted	Maximum two double jumps
Ages	No age categories	No age categories Skaters may be grouped by age	Three age categories (U10, U13, and 13&O)	Three age categories (U10, U13, and 13&O)

Table 8: Outline of STAR competitive categories for Figure Skating

The backspin is the basis for all jump rotations as well as being a variation of the basic spin upright spin position. It is required at the very earliest level of competition because it is such an important skill for a figure skater to master. Other basic spin positions include the sit spin and camel spin positions. Skaters are required to perform all three basic positions in combinations starting at the STAR 3 level. Skaters at subsequent later levels of stages of development are required to perform difficult variations of these basic spin positions in combinations to achieve greater point values.

2.5 Required Elements in Developmental Figure Skating

The figure skating elements investigated in this study are critical milestones of development and mastery is required for progression within the sport past the developmental stage.

2.5.1 The Axel Jump

The axel is a unique jump in that it is the only jump to take off forwards. It represents a milestone in skill acquisition for all skaters because it takes more time and effort to acquire than other jumps. The axel is the only jump to have a forwards take-off, and so it has an extra half revolution compared to other single jumps. All single jumps comprise one rotation in the air where a single axel is one and a half revolutions in the air. Consequently, a double axel requires two and half revolutions. The nature of the forward take-off amplifies the fear constraint in most skaters.

For a right handed skater who rotates counter-clockwise, the take-off is done from the forward outside edge of the left foot. The right (free) leg and both arms move from behind the skater and accelerate forwards and upwards to gain vertical momentum. At the point of take-off, the left (skating) leg must extend through all joints: hip, knee, ankle, and toe to reach maximum force to lift upwards into the air. As the skater is launched into the air, the arms are adducted into the rotational position and the skater adducts the take-off leg over the right leg which will become the new skating (landing) leg. The axis of rotation is slightly outside and behind the skater on the landing side (Mapelli et al., 2013).

Figure 5 shows how physical fitness is related to the performance of the axel jump in a deterministic model. A skater needs muscular strength in both the lower body for propulsion and absorption of the landing forces (Lockwood & Gervais, 1996) and upper body strength to both contribute to the rotational velocity and to stop it. Comuk & Erden (2012) stated that the number of revolutions in a jump that a skater could perform was in in all probability determined by the physical abilities of a skater (Comuk & Erden, 2012) and showed differences in performance levels of certain physical tests for skater who could perform a double axel compared to those who could not.

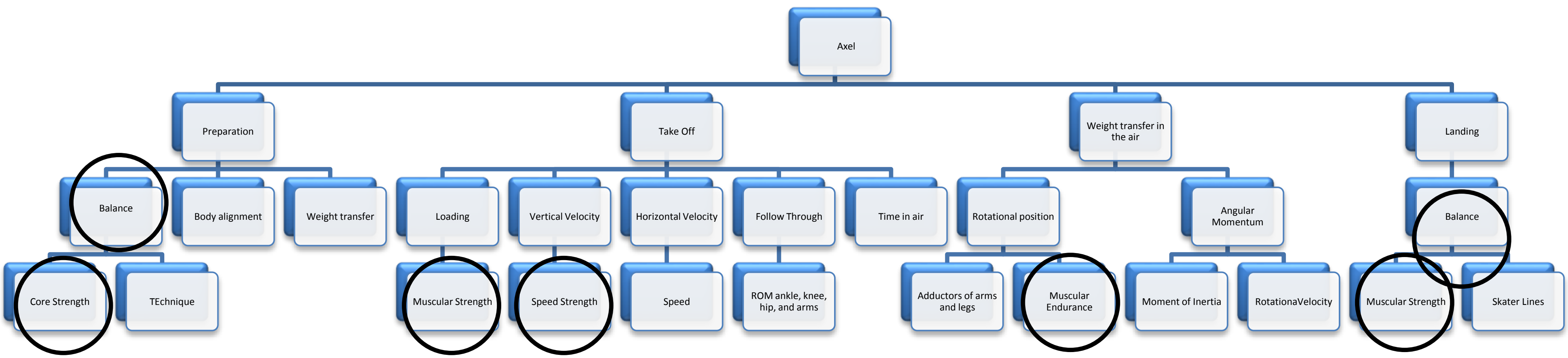


Figure 5: Deterministic Model of Axel demonstrating the physical fitness components related to the capability of performing the jump.

2.5.2 Back Spin

The backspin is considered one of the most important skills in figure skating. It is a basic spin position that must be learned at the lowest levels and provides the foundation for all jump rotations at the elite levels of figure skating. For a right handed skater, the spin is performed on the landing leg (the right), and the skater spins on the back outside edge. Figure 6 shows a photograph of a skater performing a back spin. A skater can increase rotational velocity by pulling in the limbs to decrease the moment of inertia. The rotational axis of the skater is actually outside the body, slightly to the right and behind the skater. This concept of a rotation around an axis outside of the body can be difficult for younger skaters to accomplish and they often mistake the rotational axis for the middle of their bodies, forcing them to error on spinning on a forward inside edge instead.

Mapelli and colleagues (2013) investigated backspins of past elite level skaters in an off-ice lab using a spinner device. They analyzed body angles and found that the differed in skaters with the most stable spins showing that the individuality of the skater's body affected the equilibrium. However, the study was never linked to on-ice performance of the backspin.

Figure 6: Skater Performing Backspin

2.5.3 Sit Spin

A sit spin is also critical in figure skating because it is a required spin position for achieving a combination spin, which is required in all programs at the STAR 3 level and up. In addition, most STAR 2 skaters also perform the sit spin as they have a choice between the sit spin and camel spin. The sit spin requires balance and both lower and upper body flexibility. For a right handed skater, the sit spin is performed on the left foot and requires the skater to reach a position low enough so that the buttocks of the skater is lower than the skating knee. Figure 7 shows a skater performing a sit spin with satisfying the requirements of having the buttocks below the knee. Difficult variations of this position allow a skater to score more points at higher levels.

Figure 7: Skater performing a sit spin

2.5.4 Camel Spin

A camel spin is also critical in figure skating because it is also a required spin position for achieving a combination spin, which is required in all programs at the STAR 3 level and up. A camel spin is done in the same position as a 'spiral' in figure skating and is called a camel spin because of the resemblance to a camel's hump by the buttocks of the skater while performing the camel spin. Figure 8 shows a skater performing the camel spin. It is considered more difficult than the sit spin and in order for the skater to achieve the camel spin position, they must have their free leg higher than their hip for a minimum of two rotations. The camel spin requires significant balance and both lower and upper body flexibility. For a right handed skater, the camel spin is performed on the left foot while the free leg (right) is maintained at a position higher than the hips of the skater. Difficult variations of this position allow a skater to score more points at higher levels.

Figure 8: Skater performing a camel spin.

2. 6 Physical Fitness and Prior Testing of Figure Skaters

Physical fitness is defined as a set of attributes that are either health- or skill-related, and the degree to which people have these attributes can be measure with particular tests (Caspersen, Powell, & Christenson, 1985). Physical fitness is associated with many health benefits including improvement in cardiovascular health, bone health, and mental health (Carter & Micheli, 2011; Dumith et al., 2010) related to physical activity. Physical activity is defined as any body movement that is produced by the skeletal muscles that results in energy expenditure (Caspersen et al., 1985). The American College of Sports Medicine first established physical activity guidelines for children in 1988 with the goals of optimizing bone health, muscular strength, flexibility and general health (Carter & Micheli, 2011). Current physical activity guidelines for children recommend 60 minutes of vigorous activity per day (Canadian Society for Exercise Physiology, 2012; Carter & Micheli, 2011) .

The health- and skill-related components of physical fitness are illustrated in Figure 9. Health-related components are (a) cardiorespiratory endurance, (b) muscular endurance, (c) muscular strength, (d) body composition, and (e) flexibility. Skill-related components are (a) agility, (b) balance, (c) coordination, (d) speed, (e) power, and (f) reaction time. These components are defined later in this chapter. The five health-related components are not interrelated, for example, a person can possess significant strength but lack flexibility. Health-related components of physical fitness are more vital to one’s overall health than the components associated with athletic ability (Caspersen et al., 1985).

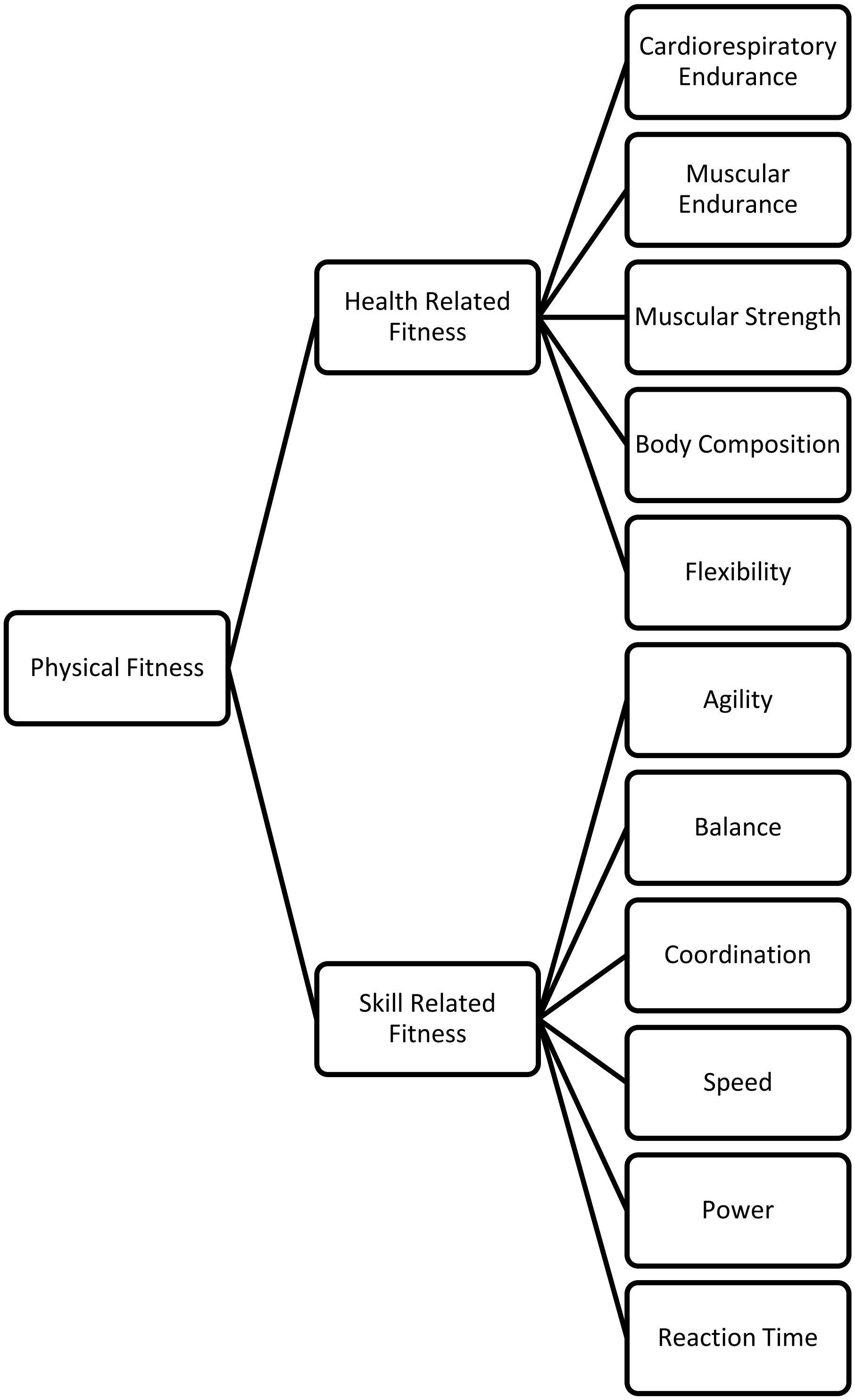


Figure 9: Components of Physical Fitness Adapted from Caspersen 1985

Poor fitness levels in children can be associated with a myriad of health related problems such as childhood obesity, diabetes, and cardiovascular diseases (Carter & Micheli, 2011). Fitness levels in children are rapidly declining despite the fact that participation in organized sports is on the rise (Carter & Micheli, 2011). Organized sports do not meet the recommended daily physical activity guidelines for children (Carter & Micheli, 2011). The misalignment between the physical demands of sports and physical fitness may be a factor in explaining the increase in sport related injuries among children (Carter & Micheli, 2011). As well, a lack of physical fitness my act as a structural constraint on the technical skills central to organized sports. This research project aims to measure health- and skill-related fitness of child participants in the early specialization sport of figure skating and will yield information that can be used to develop training programs for figure skating and possibly other sports that address the physical fitness needs of the child athletes.

2.6.1 Health-Related Fitness Components

Many of the health-related fitness components may act as constraints for athletes in various sports including figure skating.

2.6.1.1 Aerobic Endurance as a Constraint

Cardiorespiratory or aerobic endurance is a health-related component of physical fitness that related to the ability of the circulatory and respiratory systems to supply fuel during sustained physical activity and to eliminate future products after supplying fuel (Caspersen et al., 1985). Figure skaters are not highly conditioned compared to speed skaters (Mannix, Healy, & Farber, 1996). Figure skating places significant stress on the cardiovascular system with top level figure skaters achieving 100% of their maximum predicted HR early in the first minute of their programs (Mannix et al., 1996). Kjaer et al., (1992) reported that elite figure skaters displayed VO_2 values in the maximum range of 56.8 (± 1.0) and 66.7 (± 1.3) ml/kg·min for the female and male skaters, respectively; while Niinima (1982) reported a VO_2 max of 48.9 (±4.5) ml/kg·min and 58.5 (±2.4) ml/kg·min for females and males, respectively. Delistraty et al (1992) have reported lower levels in female skaters at developmental levels (e.g., 48.7 (± 7.2) ml/ kg◦min. in comparison, reported values of endurance atheltes such as cross country skiers have reported values of 77 ml/ kg◦min for females and 94 ml/ kg◦min for males (Niinimaa, 1982). Comuk & Erden (2012) compared the cardiovascular fitness levels of skaters who could execute the double axel versus those who could not. Skaters who could execute a double axel possessed greater cardiovascular fitness; however the values were poor for both groups. (e.g., 24.37 ml/ kg◦min and 21.40 ml/ kg◦min for the double axel and non-double axel groups, respectively). Figure 10 below illustrates recommended VO_2 max levels of skaters based on length of program. The skaters in Comuk & Erden (2012) would have had programs exceeding 3 minutes and showed VO_2 max levels at approximately half of the Skate Canada recommendations.

Program Length	Oxygen Uptake
2 or 2 ½ min	50 ml/kg/min
3 min	55 ml/kg/min
4 or 4 ½ min	60 ml/kg/min

Figure 10: Recommended VO_2 max levels of skaters based on length of program.
***Adapted* from Skate Canada ISPC Coaching Manual**

Although limited, there is some research examining the effect of aerobic training programs in of competitive skaters of an average level. The two intervention studies of aerobic endurance (Mannix et al., 1996; McMaster et al., 1979) investigated VO_2 max levels of competitive figure skaters. McMaster et al., (1979) reported improvements in VO_2 max levels from 44.73 cc/kg◦min to 52.51 cc/kg◦min following a 10-week off-ice interval training program. The skaters also showed improvements in a timed ½ mile skating assessment from 1:47.0 to 1:37.0 minutes. The skaters in this study also demonstrated improvements in perceived on-ice performance.

Mannix et al (1996) tested twelve female skaters and three male skaters to be randomly assigned to two different 10 week training programs. The first group only maintained their on-ice training while the second group supplemented their training with cycle ergonometer training. The researchers measured VO_2 peak (l/min), VO_2 peak (ml/kg◦min), work rate at VO_2 peak (% predicted), aerobic threshold (% VO_2 peak), work rate at aerobic threshold, and supramaximal time (min). A major finding of the research was that traditional on ice training did not improve aerobic power (Mannix et al., 1996). They concluded that competitive figure skaters possess aerobic power comparable to that of an untrained, age and gender matched population (Mannix et al., 1996).

Aerobic endurance is clearly a constraint on figure skating performance but not on the individual technical skills that are being assessed in this study. As such, it is recommended that future research on aerobic endurance related to on-ice performance of figure skating programs be conducted in the future (Mannix et al., 1996) with skaters in the Learn To Train stage of athlete development for figure skating.

2.6.1.2 Muscular Endurance as a Constraint

Muscular endurance is a health-related component of physical fitness that relates to the ability of the muscle groups to exert external force for many repetitions or successive exertions. (Caspersen et al., 1985). Muscular endurance has been measured in figure skating using sit-ups, push-ups, Biering-Sorensen Test, and timed tuck jumps (Comuk & Erden, 2012; Sands et al., 2012).

2.6.1.3 Muscular Strength as a Constraint

Muscular strength is a health-related component of physical fitness that relates to the amount of external force that a muscle can exert (Caspersen et al., 1985) . It is postulated that muscular strength is an important factor in figure skating most importantly for jumps and skating power and speed (Aleshinsky et al., 1994; Bower et al., 2010; D. King et al., 2004; Podolsky et al., 1990).

Four studies (Bower et al., 2010; Comuk & Erden, 2012; Delistraty, Reisman, & Snipes, 1992; Podolsky et al., 1990) investigated the strength parameters of figure skaters by measurements use of dynamometers yet none of the studies were consistent in their measurement equipment. Two studies utilized different hand held dynanometers for measurements of upper and lower body strength. Delistraty et al., (1992) used a Lafeyette hand grip dynamometer to assess upper body strength while Comuk and Erden (2012) used a Nicholas Manual Muscle Tester dynamometer to test lower body strength. Three of the studies (Bower et al., 2010; Comuk & Erden, 2012; Podolsky et al., 1990) related jump strength measures to performance. When investigating double axel performance, Comuk & Erden (2012) reported significant differences in muscular strength during right knee extension, and for both left and right plantar ankle flexion for skaters who could perform a double axel compared to skaters who could not. Podolsky et al., (1990) also showed that jump height is influenced during performance of both the single and double axel by knee extension strength, as well as shoulder abduction strength in the double axel. Greatest jump height was achieved with a knee extension of 240°/sec, a hip extension of 240°/sec, shoulder adduction of 300°/sec, and shoulder abduction of 300°/sec. While investigating synchronized skaters, Bower et al., (2010) showed a relationship between muscular strength in the right hip abductors to on ice acceleration as measured using a Cybex Norm Isokinetic Dynamometer.

Hand grip strength is common test used for assessing upper body strength. Niinimaa (1982) reported grip strength of highly competitive figure skaters as 30.5 ±3.7kg and 46.4 ±6.0kg for females (n = 8) and males (n=9) respectively. Delistraty et al., (1992) has shown a relationship between hand grip strength and vertical jump power in elite figure skaters. Research has also examined muscular strength in the lower body in relation to figure skating performance. Only three studies have measured the jump height of skaters' off-ice while several kinematic studies measured jump height on the ice. Podolsky et al., (1990) measured on ice jump height correlated to strength, but not off-ice measures of vertical jump height. Haguenauer et al., (2006) showed that wearing skates does alter the biomechanics of off-ice vertical jump performance in measures of squat jumps. The researchers did not collect any information on height obtained in the air to be comparable to other studies. To my knowledge, there have been no studies that directly relate off-ice vertical jump performance to on-ice jump height or performance. Delistraty et al., (1992) reported a mean vertical jump height of 37.1 (8.4) cm for skaters but the skaters were of different proficiency levels so the data is not useful for coaches, parents or skaters. Bower et al (2010) reported a mean vertical jump height of 45.16 (5.79) cm for elite synchronized skaters who do perform any jumps in their routines. No studies have reported vertical jump parameters related to skaters level or age. Delistraty et a.,l (1992) was the only study to measure vertical jump power, anaerobic capacity or anaerobic power in figure skaters though the means are averages of skaters of different levels, ages and proficiencies. This information would be useful to coaches, skaters, and parents if it was presented in comparison to skating level to determine if skaters had enough of a physical foundation.

In conclusion, there has been a significant amount of research investigating strength in figure skaters though it is not comparable to any on ice performance of elements or skills. The most significant strength parameter would be the effect of vertical jump to on-ice performance of jumps. Hence the vertical jump test will be included with skaters both with skates on and off to determine if the skaters are having any effect on the performance and are interfering with the skater's ability to jump. The Timed-Tuck jumps will also give an indication of lower body muscular endurance. Since upper body strength is also related to jumping technique and is important both for creating rotational velocity and stopping it, various measurements of upper body strength will be assessed including the Handgrip test, One-Minute Sit-Ups, One-Minute Modified Push Ups, and the Plank test for cores muscular endurance. This research project proposes to fill in some of these gaps in relation to developmental figure skaters.

2.6.1.4 Body Composition

Body composition is a health-related component of physical fitness relative to the amounts of muscle, fat, bone, and other vital parts of the body (Caspersen et al., 1985). There have been many investigations into body compositions characteristics of figure skaters which include BMI, % body fat, anthropometry and bone density and are discussed in further detail in Chapter 3.

2.6.1.4.1 Bone Density

Three studies measured the bone density of competitive figure skaters at the elite level. Prelack et al., (2012) used dual X-ray absorptiometry (DXA) to measure the bone density of total body, spine, pelvis, and leg, while Olesen et al., (2002) used ultra sound to measure the calcaneus bone density skaters' heels.   Slemenda & Johnshon (1993) used dual-energy x-ray absorptiometry (DXA) on a Lunar Instruments DPX-L to compare young female figure skaters to ascertain whether there were differences in skeletal densities at various sites compared to controls. Bone density is not a constraint on skills in figure skating though it can be related to injuries (Faigenbaum, 2000; Lipetz & Kruse, 2000; Oleson et al., 2002; Pecina et al., 1990; Prelack et al., 2012; Slemenda & Johnston, 1993) so it will not be tested in this investigation.

2.6.1.4.2 Anthropometry Measurements

Though many studies took many skinfold measurements (Leone, Lariviere, & Comtois, 2002; Moison et al., 1991; Monsma & Malina, 2005; Monsma et al., 2006; Ross et al., 1977), only 3 studies reported the somatotype proportions of competitive figure skaters (Monsma & Malina, 2005; Monsma et al., 2006; Ross et al., 1977). Calculations were done either using the Heath Carter method or unspecified.

Anthropometry measurements are not a constraint on figure skating skills except in the same relation as BMI so for this investigation, BMI will be used rather than anthropometric measurements.

2.6.1.5 Flexibility

Flexibility is a health-related component of physical fitness that the relates the range of motion available at a joint (Caspersen et al., 1985). Only three studies researched flexibility in figure skaters with two of them (Kujala, 1997; Smith, Stroud, & McQueen, 1991) relating flexibility deficits to pain in the lower back and knee pain respectively. Leone et al., (2002) was the only study to perform a basic flexibility test of figure skaters using the Sit and Reach Test.

2.6.2 Skill-Related Fitness Components

Many of the skill-related fitness components may act as constraints for athletes in various sports including figure skating.

2.6.2.1 Agility

Agility is skill-related component of physical fitness that relates to the ability to rapidly change the position of the entire body in space with speed and accuracy (Caspersen et al., 1985). Agility scores have not been found in any of the existing English based literature involving figure skaters. Comuk & Erden (2012) acknowledged a study of agility previously conducted by Comuk but it was published in a Turkish journal (Comuk & Erden, 2012).

2.6.2.2 Balance

Balance is a skill-related component of physical fitness that relates to the maintenance and of equilibrium while stationary or moving (Caspersen et al., 1985). Balance investigations in figure skaters have been confined to laboratory tests and have not been related to any on ice performance of skaters of any level, proficiency or discipline (Alpini, Mattei, Schlecht, & Kohen-Raz, 2008; Kovacs, Birmingham, Forwell, & Litchfield, 2004; Saunders, Hanson, Koutakis, Chaudhari, & Devor, 2013). Despite the lack of connection, studies specific to figure skaters have concluded that off-ice conditioning programs emphasizing balance and ankle stability should be incorporated into the normal training programs of skaters (Dubravcic-Simunjak et al., 2003; King, 2005; Lipetz & Kruse, 2000; Saunders et al., 2013).

Kovacs et al (2004) investigated the effect of a 4-week neuromuscular training (NMT) program on the postural control skaters of different disciplines. Using a force place, they measured the path length of the centre of pressure displacements over 5 different balance tests (single leg stance with eyes open, single limb stance with eyes closed, jump landings with eyes open, jump landing with eyes closed, and the single lib stance with skates on and eyes open). They tested all the skaters before and after a 4 week off ice training program in which one group received neuromuscular training (NMT) program and the other received a basic exercise training program. NMT group showed improvement in path length with respect to the two most difficult tests; the landing backward from a platform with eyes closed, and the single limb balance with skate on and eyes open. However, these skills are not directly related to on ice performance firstly, because skaters are never standing stationary while balancing on one limb on the ice, and secondly, to land multiple rotational jumps successfully, the skater must actually still be in a rotational position upon landing on the ice and then unwinding into the rotational position to stop the rotation. Skaters do not land jumps in the actual landing position as the force of the rotation would disrupt the balance. The researchers did show that the neuromuscular trained group had improved more than the basic exercise group in all of the balance tests.

In comparison, the only other study to utilize an postural control intervention was Saunders et al., (2012) whom wanted to assess whether the level of the skater had an predisposed the effectiveness of a 6 week neuromuscular training program and their baseline measurements. They also tested skaters on the single limb stance, and the single limb landing. Saunders and colleagues hypothesized that the percent change would be greater in the skaters of lower skill than higher skill because of the ceiling effect but their results proved contrary. The higher skilled skaters improved more than the less skilled skaters but the results were only significant in one test of single leg stance. The researchers believed that their results were due to the fact that the higher skilled skaters was the fact that they just completed more revolutions in the air during the jump and that there was no real difference in their ability to land a stationary jump. They also they believed that their small sample size (n=15 for low skilled, and n=11 for highly skilled) affected the significance of their results. Both the above mentioned studies used different force plate technology on different types of skaters so the results are not directly comparable.

In contrast, Alpini et al., (2012) studied the postural control of synchronized skaters who use of force plates and posturography. By adding a 10 cm foam pad to the pressure plate, the task of standing stably on the pressure plate was made more difficult. Skaters performed the two tests with both eyes open and closed. In comparison to controls, the synchronized skaters showed higher weight distribution values (less balance), then the controls did on the less challenging pressure plate conditions. They concluded that the foam variation of the plate resembled the unsteady surface of the ice and that the skaters were better able to optimize their antigravity alignment (Alpini et al., 2008). The felt that this effect was similar to patterns of adaptations of what happens on ship, where the after becoming proficient at maintaining balance on an unsteady surface, balance on stable ground can worsen (Alpini et al., 2008).

There has been extensive interest and research in the balance reflexes of figure skaters at the elite levels. A team of researchers from Italy Dario Alpini, Mirco Botta, Valentina Mattei, and Davide Tornese have completed a series of studies related to balance and vestibular ocular reflexes (Alpini, Botta, Mattei, & Tornese, 2012; Alpini, Botta, Mattei, & Tornese, 2010; Tornese et al., 2011). They have investigated the effect of a virtual reality training program to improve balance in elite ice dancers (Tornese et al., 2011), and whether the different disciplines of figure skating show differences in vestibular-ocular reflexes (Alpini et al., 2012; Alpini et al., 2010). Other studies have investigated otolithic inputs and their effect on vestibular stimulation (Tanguy, Quarck, Etard, Gauthier, & Denise, 2008), ad how the vestibular reflex is related to motion sickness in figure skaters (Tanguy et al., 2008). None of these aspects of balance will be investigated as they are not a constraint on any skill acquisition of developmental figure skaters.

Of the studies to directly investigate balance as a component of figure skating (Alpini et al., 2008; Kovacs et al., 2004; Saunders et al., 2013), none of them have connected the results to on-ice performance of skills. All of these studies compared balance tests of both eyes open and eyes closed. In this study, a much simpler method (Stork Stand) will be used as field test for the assessment of balance in figure skaters and will test both legs, eyes open and closed. As well, the standing spiral has been chosen as a balance assessment because of the importance of the spiral position as a single limb balance move in figure skating.

2.6.2.3 Coordination

Coordination is skill-related component of physical fitness that relates to the ability to use the senses, such as sight and hearing, together with body parts in performing motor tasks smoothly and accurately (Caspersen et al., 1985). Coordination will not be investigated in this study as it is not an underlying component or constraint to the proposed skills for study.

2.6.2.4 Power

Power is skill-related component of physical fitness that relates to the rate at which one can perform work (Caspersen et al., 1985). Power will not be investigated in this study as it is not an underlying component to the proposed skills for study.

2.6.2.5 Speed

Speed is a skill-related component of physical fitness that relates to the ability to perform a movement within a short period of time (Caspersen et al., 1985). Speed will not be investigated in this study as it is not an underlying component or constraint to the proposed skills for study.

2.6.2.6 Reaction Time

Reaction time is a skill-related component of physical fitness that relates to the time elapsed between stimulation and the beginning of the reaction to it (Caspersen et al., 1985). Reaction time will not be investigated in this study as it is not an underlying component or constraint to the proposed skills for study.

2.7 Testing Physical Fitness in Figure Skating

Figure skating is a sport that has undergone major changes over the past 50 years with the most recent changes in the last 10 years involving the implementation of a new judging system. As the sport has changed, it has demanded greater athleticism and required the successfully performance of more difficult jumps at younger ages. The US Figure Skating Association is ahead of other NSO’s in terms of relating physical fitness to skill level in figure skating. They have created a program they call STARS for standardized testing and recognition system of figure skaters. They travel to skating clubs across the country and test figure skaters ages 6 and older and of the preliminary level and above and created a comprehensive database of the results. Skaters who participate in the program will receive their results and a percentile ranking of where they lie in relation to both their age and level of skating. However, they still do not compare any information collected to performance levels. Though this information is still extremely useful for skaters, parents and coaches.

Previously, tests of physical fitness have been administered on figure skaters to determine the physical demands of the sport (Bower et al., 2010; Comuk & Erden, 2012; McMaster et al., 1979; Podolsky et al., 1990; Sands et al., 2012; Smith et al., 1991). To date, investigations have mainly focused on muscular strength, muscular endurance, and power as it relates to jumping.

2.8 Other Figure Skating Research Areas

Many aspects of research involving figure skaters have investigated nutrition and eating disorders, psychology, and the judging of the sport. However some physical characteristics including age of menarche, injuries, and kinematics involving jumping have been researched.

2.8.1 Kinematics of Elements as Task Constraints

Amongst the literature, there are seven articles to investigate kinematics and biomechanics of elements in figure skating by analyzing elite skaters only. Three of the articles have been dedicated to the double axel jump and higher (Albert & Miller, 1996;

King et al., 1994, 2004) while one analyzed the backspin which is crucial to jump technique (Mapelli et al., 2013). One was a review of the previous articles of jump kinematics (King, 2005). All the kinematic articles were conducted on skaters who were very skilled in the sport at either, the elite level, or at the least aspiring to be elite level (Albert et al, 1996). In total, data was collected on 93 skaters, with the majority being male (58) compared to females (35). Two studies on kinematics of figure skaters did not involve any on ice testing measures (Haguenauer, Legreneur, & Monteil, 2006; Mapelli et al., 2013; Sands et al., 2012). The ages of the skaters studied for kinematics and biomechanics is not completely reliable since the Mapelli et al., (2013) study on backspins contained several retired elite skaters who were now coaches or had moved on but were not currently competing anymore. However, it is interesting to note that in King studies, the elite male skaters were in their early 20's. All the kinematic studies involved skaters of substantial caliber of skating and performed on technique related to jumping performance. The studies are quite relevant in spite of the changes to the sport because of the increase in the importance of jumps in the programs of figure skaters.

2.8.2 Cognitive Abilities of Figure Skaters as Functional Constraints

Four articles studied cognitive constraints for learning skills such as skilled memory of a figure skater, responses to different instruction techniques and the use of self-modelling. None of these articles contained information on any physical data such as height, weight, or BMI of the skaters. Skating levels of skaters was limited to descriptions of skilled versus novice (not the Novice level as an official skating category). Guillot & Collet (2004) defined their expert skaters as having more than 10 years of experience. These subjects were given the Group Embedded Figures Test and the athletes in acrobatic sports including figure skating, were predominantly more field independent. In contrast, the skaters in Haguenauer et al., (2005) had only been skating for 1-2 years.

Two of the studies utilized intervention strategies involving how skaters learn skills. Haguenauer et al., (2005) observed the effects of using verbal instructions and demonstrations for learning a complex skill in figure skating.

2.8.3 Age of Menarche

Figure skating has been associated with delayed menarche in young girls (Moison et al., 1991; Vadocz et al., 2002). Two studies identified the approximate ages of menarche in figure skaters. Average age of menarche is 12.8 years (Monsma, 2008) . Malina et al., (2002) found that skaters' age of menarche was 13.6 (1.2) years for competitive skaters and that elite skaters were matured even later than test stream skaters. In contrast, Monsma (2008) found 75% of the skaters who had reached menarche to be average maturing (menarche 11.9-13.8 years), and 25% to be late maturing (menarche > 13.8 years). Moison et al., (1991) reported onset of menstruation as incidence density ratios and did not report an actual age for menarche for any specified group. Participation in aesthetic sports such as figure skating is associated with later age of menarche (Moison et al., 1991). However, participation in these sports does not cause late onset of menstruation which was also found to be correlated with the mother's age of menarche (Moison et al., 1991) and is more a result of self-selection into these types of sports (Kaleth & Mikesky, 2010). Monsma (2008) compared the different disciplines of figure skating and found that skater's self-perceptions where influenced by their pubertal timing. The later maturing skaters reported higher confidence in their endurance but lower feelings regarding their health compared to the average maturing skaters (E. V. Monsma, 2008). Menarchal status, endomorphy (r=-.67), and ectomorphy (r=.66) also showed strong correlations to self-perception (E. V. Monsma et al., 2006). The younger pre-menarchal skaters were ectomorphic and less concerned with their body fat and sport competence while the older more endomorphic skaters were more concerned with body fat. One study (Dubravcic-Simunjak et al., 2006) showed the age of menarche is higher in elite synchronized skaters (median 13 years) which aligns with the fact that the benefits of body type associated with early age of menarche are not a requirement in synchronized skating in which there is little to no jumping component.

2.9 Conclusion

Figure skating is an early specialization sport which is mostly associated negatively to development of athleticism in sport and children however no studies have been conducted to verify claims of detriments to growth and maturation in early specialization sports, including figure skating. There have been some suggestions of possible benefits of early specialization such as increased fitness such strength, flexibility and bone density but research has directly linked the benefits of early specialization either. The Long Term Athlete Development Model is a pathway set out by sport organizations as a guideline for the development of young athletes to optimize the benefits of sport participation and performance for all levels of athletes though it is vague to relay any useful information. Using Newell's model of constraints, physical fitness can be a possible constraints in figure skating performance of certain technical skills.

CHAPTER THREE SYSTEMATIC REVIEW OF PHYSICAL FITNESS IN FIGURE SKATERS

Objective: The purpose of this review was to critically examine the existing literature related to health related and skill related physical fitness amongst figure skaters.

Methods: A systematic and evidence based approach was used to critically evaluate the existing literature related to health related and skill related physical fitness amongst figure skaters. All articles were screened according to standardized evaluation criteria developed by a panel of experts.

Results: A total of 33 investigations involving 2, 650 figure skaters were included in the analysis. Of the 33 studies, only15 documented physical fitness related tests and results.

3.1 Introduction

Figure skating is a unique sport in that it is also an art and shares many similarities to some disciplines in the performing arts. Moreover, the demands placed on a figure skater are varied. Johnny Heater, an MC for the National Figure Skating Championships, commented that "to be a good figure skater, one must have the balance of a tightrope walker, the endurance of a marathon runner, the aggressiveness of a football player, the agility of a wrestler, the nerves of a golfer, the flexibility of gymnast, and the grace a ballet dancer" (McMaster et al., 1979). According to the NCCP Developing Athletic Abilities (Canadian Association of Canada, 2008), figure skating is a sport that requires high levels of speed strength, strength endurance, and maximum strength relative to the body weight. For example, relative strength (strength in relation to body weight and size) is a significant parameter in determining the height of jumps as it influences jump take-off technique, as well as the successful performance of jump landings (Comuk & Erden, 2012; Podolsky et al., 1990; Smith et al., 1991). Figure skaters require a certain level of physical fitness to be able to participate successfully in the sport. Figure skaters need a solid physical foundation that includes both health-related and skill-related physical fitness such speed, strength, endurance and flexibility (Skate Canada, 2010) . Little is known about the psychological demands of the sport and appropriate on ice and off-ice training techniques (Pies et al., 1998).

3.2 Methods

3.2.1 Inclusion and Exclusion Criteria

A systematic and evidence based approach was used to examine critically the figure skating literature as it relates to physical and skill related fitness. Only investigations examining physical fitness were included, including studies related to injuries. Articles with a focus on sport psychology, nutrition, exercise induced complications, or figure skating judging were eliminated. No restrictions were imposed on study design. Only published, English language investigations were included.

3.2.2 Search Strategy

An electronic search strategy was developed and performed as identified below. Literature searches were conducted in seven electronic bibliographical databases:

- Web of Science (February 5th, 2014)
- SPORTDiscus (February 5th, 2014)
- Academic Search Complete (February 9th, 2014)
- Ovid Sp (February 9th, 2014)
- PSYCHInfo (Febuary 9th, 2014)
- CAB (Febuary 9th, 2014)
- Eric (Febuary 9th, 2014)

Various forms of keywords figure skater, figure skating, and figure skate by entering ‘figure skat*” into the search protocols. Original citations were downloaded into an online management system (RefWorks, Bethesda, MD., USA) citation management system.

3.2.3. Screening

Two reviewers (JB and RT) independently screened the titles and abstracts of all citations to identify articles for potential inclusion. Duplicate citations were removed, while the full text of apparently relevant articles were retrieved for further screening and data extraction. The reviewers were not blinded to author or journal. Studies excluded during the screening process were recorded, as well as the reason for exclusion (Figure 11).

3.2.4. Data Extraction

All data was extracted using a standard template. Data extraction details included where the study was conducted (country of origin), study design, participant characteristics (i.e., age, gender, height, weight, BMI, skin fold measurements, level of skating, and skating discipline), sample size, study methodologies, outcome measures, and the conclusion that was reached.

Feb 5th, 2014		**Results after removal of Duplicates**
Web of Science	330	330
Sport Discuss	215	188
Feb 9th, 2014		
Academic Search Comlete	142	64
Eric	9	4
CAB	100	89
Ovid Sp	141	136
Psych Info	112	84
Total	**1064**	**895**

Citations excluded after scanning titles (n = 739)
Abstracts assessed for elgibilty after scanning titles (n = 156)

Citations excluded after scanning abstracts (n = 104)
Full articles included after scanning abstracts (n = 32)

Articles excluded after Full Review (n = 0)
Articles included after full review (n = 32)

Additional articles added based on reference lists (n=1)
Articles included for full review (n=33)

Figure 11: Results of literature search

3.3. Results

A total of 1064 citations were identified during the electronic database search (figure 11). Of these citations, 330 were identified in Web of Science, 215 in SPORTDiscus, 142 in Academic Search Complete, 141 in OvidSp, 112 in PSYCHInfo, 100 in CAB, and 9 in Eric. A total of 169 duplicates were removed leaving 895 citations. After scanning titles and abstracts, a total of 843 were removed leaving a total of 52 articles for review. From these articles, 6 were excluded leaving 46 articles for inclusion in the systematic review. The reasons for exclusion included review articles, conference proceedings, positions statements, commentaries, letters, and other. In addition, 2 articles were added based screening the reference lists. At total of 48 articles were included in the systematic review of the literature.

3.3.1. Investigation Characteristics

The overall investigation characteristics are presented in Tables 9 and 10. Over a span of 45 years, research containing physical fitness information of figure skating has included actual physical fitness studies (45 %), injuries and or their prevention (27 %), physical fitness related to injuries and or their prevention (12%), physical fitness as bone density of figure skaters (9%), and biomechanics of jumps and kinematics of figure skating elements in relation to physical fitness (6%). Many studies investigated physical fitness in relation to other aspects of skater development (27%).

The greatest number of investigations have examined single skaters (51%), followed by studies where the discipline was not specified (21%), mixed discipline studies (15%), synchronized skaters (9%), and pairs (3%) respectively.

Many studies contained small sample sizes, the majority of them having less than 20 participants (45%), followed by studies that contained between 20-50 figure skaters (30%), 51-100 figure skaters (12%), 101-150 figure skaters (8%), and studies with more than 150 skaters (5%).

Mean ages of adolescent figure skaters where the most researched in the studies (58%). Nine studies (27%) containing figure skaters of mean ages of reaching adolescence 10-14 years while skaters in their early twenties made up four of the studies (12%). One study contained adult skaters over 30 years of age (3%). Studies with mean ages of skaters in their late twenties did not comprise any of the studies (0%). As well, no studies contained a mean age of less than 10 for the investigations (0%

Characteristic	No. (%)
Skating discipline	
Single skaters	17 (51%)
Not specified	7 (21%)
Mixed disciplines	5 (15%)
Synchronized skaters	3 (9%)
Pairs	1 (3%)
Ice dancers	0 (0%)
Number of participants per study	
0-20	33 (45%)
21-50	22 (30%)
51-100	9 (12%)
101-150	6 (8%)
>150	4 (5%)
Areas of investigation‡	
Physical fitness	15 (45%)
Injuries and/or prevention	9 (27%)
Physical fitness and injuries/prevention	4 (12%)
Physical fitness and bone density	3 (9%)
Physical fitness and biomechanics	2 (6%)
Age (yrs)	
<10	0 (0%)
10-14	9 (27%)
15-19	19 (58%)
20-24	4 (12%)
25-29	0 (0%)
>30	1 (3%)

Table 9: Investigation Characteristics

Table 9 summarizes the figure skating discipline characteristics of the studies. The majority of research participants have been single skaters (45%), followed by synchronized skaters (23%). Many studies investigated parameters where the discipline of the figure skater was not necessary information or skaters were not an age yet to specialize (22%). Pairs (5%) and ice dancers (4%) were the least utilized disciplines for research.

3.3.2 Participant Characteristics

Table 10 shows the participant characteristics for the research on figure skaters. The majority of research has been done on skaters aged 15-19 years of age (71%), followed by skaters aged 10-14 years (19%), skaters aged 20-24 (6%), and adult skaters of ages 30 and over (5%).

Characteristic	No. (%)
Age (yrs)	
<10	0 (0%)
10-14	493 (19%)
15-19	1877 (71%)
20-24	169 (6%)
25-29	0 (0%)
>30	130 (5%)
Participants by Skating Discipline	**N=2650 figure skater**
Single Skaters	1205 (45%)
Synchronized Skaters	619 (23%)
Unspecified Disciplines	577 (22%)
Pairs	139 (5%)
Ice Dancers	110 (4%)
*Controls (non-figure skaters)	211 (7%)
** - % of total participants (2,861)*	

Table 10: Participant Characteristics (n = 2, 650)

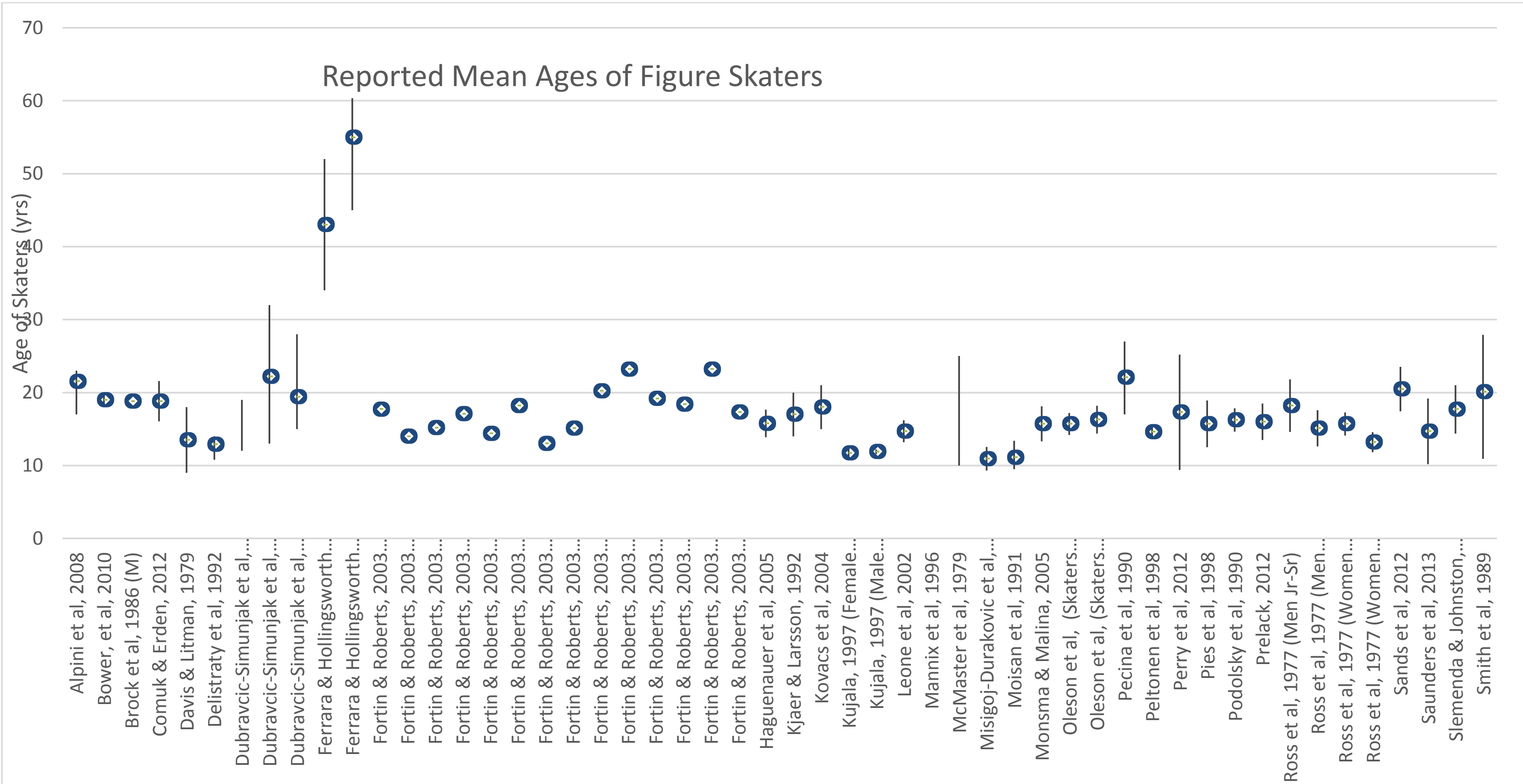


Figure 12: Graph of Ages of Figure Skaters

3.3.2.1 Ages of Figure Skaters

All of the studies included information regarding the ages of the figure skaters being investigated. Figure 12 shows the that the mean ages of figure skaters ranged from 10.92 (Misigoj-Durakovic et al., 2005) to 23.2 (Fortin & Roberts, 2003) years of age while one additional study included adult figure skaters with mean ages of 43 and 55 for females and males respectively (Ferrara & Hollingsworth, 2007).

3.3.3 Health-Related and Skill-Related Measures of Physical Fitness

Table 10 outlines the aspects of physical and skill related physical fitness in figure skaters that have been investigated.

Areas of Investigation	Studies	Measures	Type of Skaters used in the Study	n
Anthropometry	Ross, Brown, Yu, & Faulkner, 1977	Somatotype calculations using skin fold and girth measurements	National Development Camp skaters (Novice through Senior – Skate Canada)	46 (19M, 27F)
	Delistraty, Reisman, & Snipes, 1992	Unspecified anthropometric measurements	Preliminary through Junior levels	13 F
	Leone, Lariviere, & Comtois, 2002	Somatotype calculations using 7 skin fold and girth measurements	Unspecified levels of figure skaters	46 F
	Misigoj-Durakovic et al., 2005	24 anthropometric measures	Premenarchal figure skaters	12 F
	Monsma & Malina, 2005	15 anthropometric measurements including skeletal breadths, skin fold and limb circumferences	Comparison of Elite, PreElite, Test, and Freeskaters, Ice Dancers and Pair Skaters	161 F
Aerobic Endurance; VO_2 max; Blood Lactate; Anaerobic Threshold (AT); % Hematocrit	Comuk & Erden, 2012	Cooper 12 Min/Run Walk Reported values in total distance (m) Double Axel = 1595, No Double Axel =1462	National Level (Senior =10, Junior = 10) (Double axel group = 9, non Double axel group = 11)	20 F
	Delistraty, Reisman, & Snipes, 1992	48.7 (± 7.2) ml/ kg◦min Range 39.2 – 58.9 ml/ kg◦min	Preliminary through Junior levels	13 F

Areas of Investigation	Studies	Measures	Type of Skaters used in the Study	n
		VO_2 max predicted by submaximal cycle ergometer; % Hematocrit 40.1 ± 1.9%		
	Kjaer & Larsson, 1992	Male =66.7 (1.0), Female = 56.8 (1.0) ml/ kg◦min Range 54.7 – 68.8 ml/ kg◦min; VO_2 max predicted by treadmill BLa = 2.0 ± 0.05 mM BLa(post 4 min run) = 8.0 ± 0.6 mM Resting HR (F)= 53 ± 2 Resting HR (M)= 58 ± 3	Elite skaters on Danish National Team	8 (3M, 5F)
	*Mannix, Healy, & Farber, 1996	VO_2 max by cycle ergometer Gr 1 (control): VO_2 peak, pre =44.2 ± 2.2, post = 41.4 ± 1.6 ml/kg◦min; VO_2 peak % (%predicted), pre =100 ± 5%, post = 92± 4%; anaerobic threshold (AT %), pre = 74± 3%, post = 73.3%; Supramaximal Time, pre = 0.87±0.12, post = 0.94±0.12 min Gr 2: (10 wk	Regional to National levels Senior n=2 Junior n=1 Novice n=9 Intermediate n=3	15 (12F, 3M)

Areas of Investigation	Studies	Measures	Type of Skaters used in the Study	n
		endurance training program) VO_2 peak, pre =50.7 ± 3.6, post = 55.9 ± 3.3 ml/kg◦min; VO_2 peak % (%predicted), pre =110 ± 7%, post = 121± 6%; anaerobic threshold (AT %), pre = 80± 2%, post = 83± 2%; Supramaximal Time, pre = 1.31±0.18, post = 2.69 ±0.66 min		
	*McMaster, Liddle, & Walsh, 1979	VO_2 max, pre = 44.73 (range 36-52) cc/kg◦min, post = 52.51 cc/kg◦min; timed ½ mile skater effort, pre = 1:47.0, post = 1:37.0	Preliminary to Eighth Test	Not reported
***Intervention**				
Vertical Jump; Anaerobic Power	Bower et al., 2010	Vertical Jump Height = 45.16 ± 5.79 cm Vertical Jump Tester	Elite World Level Synchro Skaters attending college	27 F
	Delistraty, Reisman, & Snipes, 1992	Vertical Jump Height = 37.1 ± 8.4 cm; Vertical Jump Power = 64.8 ± 9.2 kgm/sec; Anaerobic Capacity (30s) =	Preliminary through Junior levels	13 F

Areas of Investigation	Studies	Measures	Type of Skaters used in the Study	n
		34.4 kpm/kg/min; Peak Anaerobic Power (>5s)= 42.7		
	Haguenauer, Legreneur, Monteil, 2006	Squat Jump under 3 conditions: barefoot (BF), light weight = 1.5 kg (LW), and with skates on (SK), skaters filmed while jumping on force plate to determine angles of take-off, for analysis of joint coordination.	National – International Level	10 (6M, 4F)
Strength (dynamometer measurements)	Bower et al., 2010	Lower Body Extremity Strength Using Cybex Norm Isokinetic Dynamometer Measurements: Hip adduction, right, left; Hip abduction, right, left	Elite World Level Synchro Skaters attending college	27 F
	Comuk & Erden, 2012	Lower Body Extremity Strength Tests using Nicholas Manual Muscle Tester	20 National Level (Senior =10, Junior = 10) (Double axel group = 9, non Double axel group = 11)	20 F

Areas of Investigation	Studies	Measures	Type of Skaters used in the Study	n
		Measurements: Hip flexor , right, left; Hip Extensors, right, left; Hip adductors, right, left, Hip abductors, right, left; internal rotation, right, left; external rotation, right, left Knee extension, right, left; Knee flexion, right, left Ankle dorsi flexion, right, left; Ankle plantar flexion, right, left		
	Delistraty, Reisman, & Snipes, 1992	Hand Grip Strength using Lafeyette hand dynamometer	Preliminary through Junior levels	13F
	Podolsky, Kaufman, Cahalan, Aleshinsky, & Chao, 1990	Upper and lower body extremity strength tests using Cybex II isokinetic dynamometer system and correlations with jump height measured with two high speed cameras Measurements: Shoulder abduction, Shoulder adduction, hip extension,	Selected skaters for junior sport science camp	18 (8F, 10M)

Areas of Investigation	Studies	Measures	Type of Skaters used in the Study	n
		hip flexion, knee flexion; knee extension		
Muscular Strength and Muscular Endurance	Bower et al., 2010	Maximal strength as determined by 1 RM squat test	Elite World Level Synchro Skaters attending college	27 F
	Comuk & Erden, 2012	Muscular Strength Endurance Measurements: 1 Minute Sit-Ups; 1 Minute Modified Push-Ups Test; Beiring-Sorensen Test	20 National Level (Senior =10, Junior = 10) (Double axel group = 9, non Double axel group = 11)	20F
	Leone, Lariviere, & Comtois, 2002	Muscular Strength Endurance Measurements: 50 Push –Ups per Minute till exhaustion: 25 Burpees per Minute till Exhaustion	Unspecified levels of figure skaters	46F
Other Basic Physical Testing				
Flexibility	Smith, Stroud, & McQueen, 1991	Thigh muscle flexibility	Elite Junior Figure Skaters	46F
	Kujala, 1997	Lower lumbar flexibility	Not specified	17F

Areas of Investigation	Studies	Measures	Type of Skaters used in the Study	n
	Leone, Lariviere, & Comtois, 2002	Sit and Reach Test	Unspecified levels of figure skaters	46F
On Ice Performance Measures	Bower et al., 2010	On Ice Acceleration (18 yard Sprint) On Ice Speed Test (Timed Single Lap Sprint) 4.5 Min Lap count	Elite World Level Synchro Skaters attending college	27F
	Podolsky, Kaufman, Cahalan, Aleshinsky, & Chao, 1990	On Ice Jump Height of Axels and Double Axels measured through video analysis Take off characteristics of	Selected skaters for junior sport science camp	18 (8F, 10M)
	Albert & Miller, 1996	Axel Jumps	Not specified	16 (8F, 8M)
	King, Arnold, Smith, 1994	Kinematic Analysis of Axel jumps	Elite Skaters	5M

Table 11: Health-Related and Skill-Related Physical Fitness Measures

3.3.3.1 Muscular Strength and Muscular Endurance

Four studies (Bower et al., 2010; Comuk & Erden, 2012; Delistraty et al., 1992; Podolsky et al., 1990) investigated the strength parameters of figure skaters by measurements of dynamometers. Three of the studies (Bower et al., 2010; Comuk & Erden, 2012; Podolsky et al., 1990) related jump strength measures to performance. All studies included skaters at an elite level of their disciplines. None of the studies were consistent in their measurement equipment. Delistraty et al., (1992) and Comuk & Erden (2012) used hand held devices using a Lafeyette hand grip dynamometer and a Nicholas Manual Muscle Tester dynamometer respectively. Delistraty et al., (1992) investigated hand grip strength of skaters of different proficiencies and found a correlation between weight with handgrip strength and vertical jump power and for vertical jump power with hand grip strength. Comuk & Erden (2012) reported that the increased strength was necessary for double axel performance. They reported significant differences in strength in the right knee extension, and both left and right plantar ankle flexion for skaters who could perform double axels compared to skaters who could not. Podolsky et al., (1990) compared strength measurements to jump height of both single and double axels and found that highest correlations for jump height of an axel were obtained with the knee extension (240°/sec), hip extension (240°/sec), should adduction (300°/sec) and shoulder abduction (300°/sec). Both the single and double axel showed knee extension as the primary strength parameter but that in the double axel, shoulder abduction was an important secondary strength parameter. Bower et al (2010), included only synchronized skaters and showed a moderate but significant correlation of right hip abductors to on ice acceleration.

3.3.3.2 Vertical Jump and Anaerobic Power

Only three studies have measured the jump height of skaters' off-ice while several kinematic studies measured jump height on the ice. Podolsky et al., (1990) measured on ice jump height correlated to strength, but not off-ice measures of vertical jump height. Haguenauer et al., (2006) showed that wearing skates does alter the biomechanics of off-ice vertical jump performance in measures of squat jumps. The researchers did not collect any information on height obtained in the air. To the authors' knowledge, there have been no studies that directly relate off-ice vertical jump performance to on-ice jump height or performance. Delistraty et al., (1992) reported a mean vertical jump height of 37.1 (8.4) cm for skaters of different proficiency levels. Bower et al., (2010) reported a mean vertical jump height of 45.16 (5.79) cm for elite synchronized skaters who do perform any jumps in their routines. No studies have reported vertical jump parameters related to skaters level or age. Delistraty et al (1992) was the only study to measure vertical jump power, anaerobic capacity or anaerobic power in figure skaters though the means are averages of skaters of different levels, ages and proficiencies.

3.3.3.3 Aerobic Endurance

Figure skaters are not highly conditioned compared to speed skaters (Mannix et al., 1996). Figure skaters places significant stress on the cardiovascular system with top level figure skaters achieving 100% of their maximum predicted HR early in the first minute of their programs (Mannix et al., 1996).

The two intervention studies of anaerobic endurance (Mannix et al., 1996; McMaster et al., 1979) reported means of average competitive skaters unlike the majority of studies to measure elite level performance. Kjaer & Larsson (1992) reported that the elite figure skaters had VO_2 max range of 58.7-64.8 ml/kg·min.

3.3.3.4 Flexibility

Only three studies researched flexibility in figure skaters with two of them (Kujala, 1997; Smith et al., 1991) relating flexibility deficits to pain in the lower back and knee pain respectively. Leone et al., (2002) was the only study to perform a basic flexibility test of figure skaters using the Sit and Reach Test.

3.3.3.5 Body Composition

Body composition was measured using a variety of different methods across different studies. Of the methods used, BMI was the most common but also skin fold measurements, % body fat and anthropometry were used.

3.3.3.5.1 BMI/Skin folds/% Body Fat

Figure 13 shows the means of BMI's recorded for Figure Skaters. Six studies of figure skaters show healthy BMI's ranging from the 25th percentile to 60th percentile (Comuk & Erden, 2012; Kujala, 1997; Misigoj-Durakovic et al., 2005; Monsma & Malina, 2005; Pies et al., 1998) as per the CDC. Figure skaters in Leone et al's study (2002) used skin fold measurements but reported height values in the 20th percentile, but body mass in the 30th percentile. Additionally, Oleson et al., (2002) reported BMI's as pounds per square inch (mean 1.9 ± 0.2). Percentage of body fat for female figure skaters ranged from 15.4 to 23.2% in six studies (Figure 14). Only one study reported % body fat for male skaters at 17% (1%)

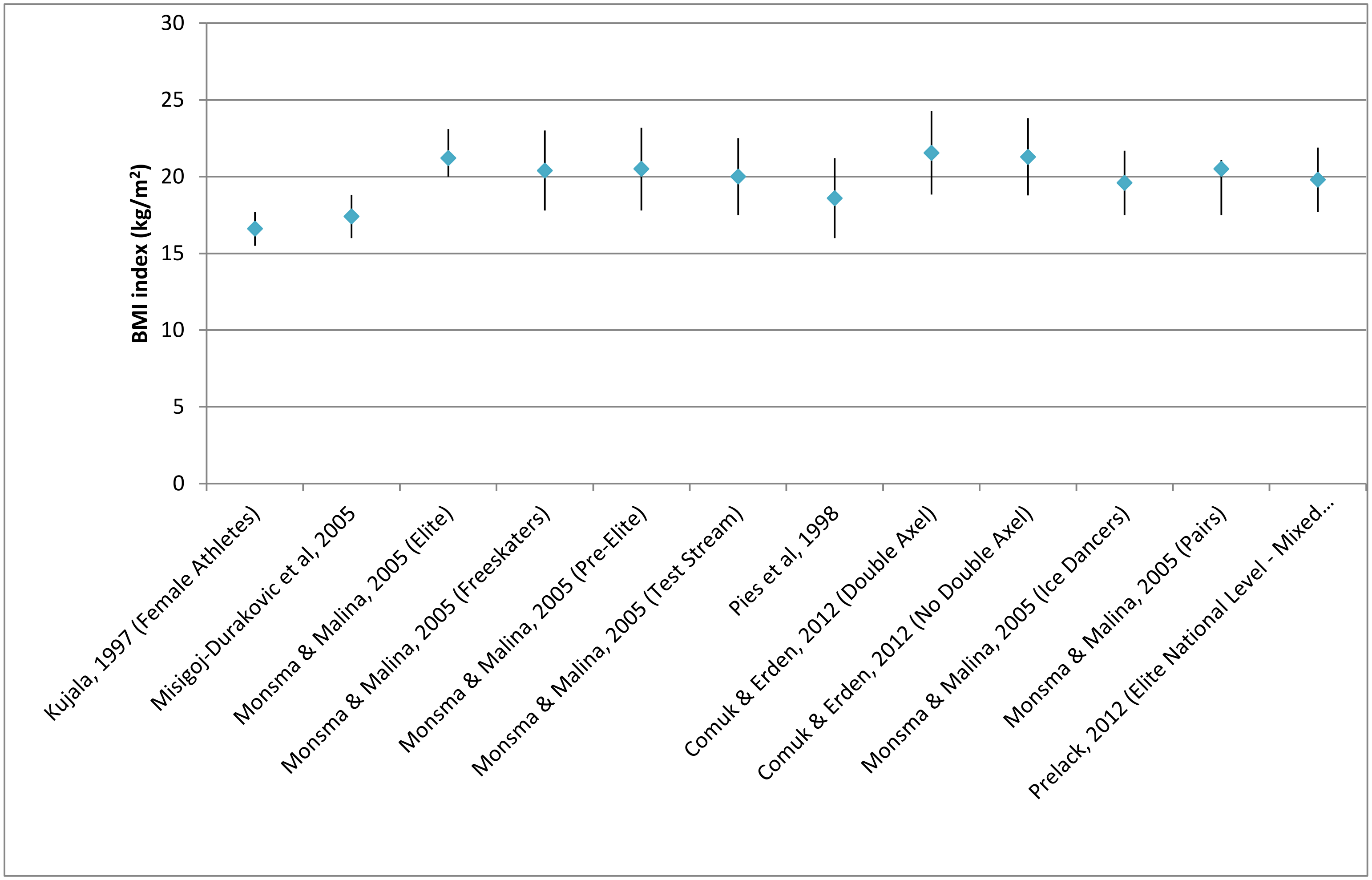


Figure 13: BMI For Figure Skaters involved in the Research Studies

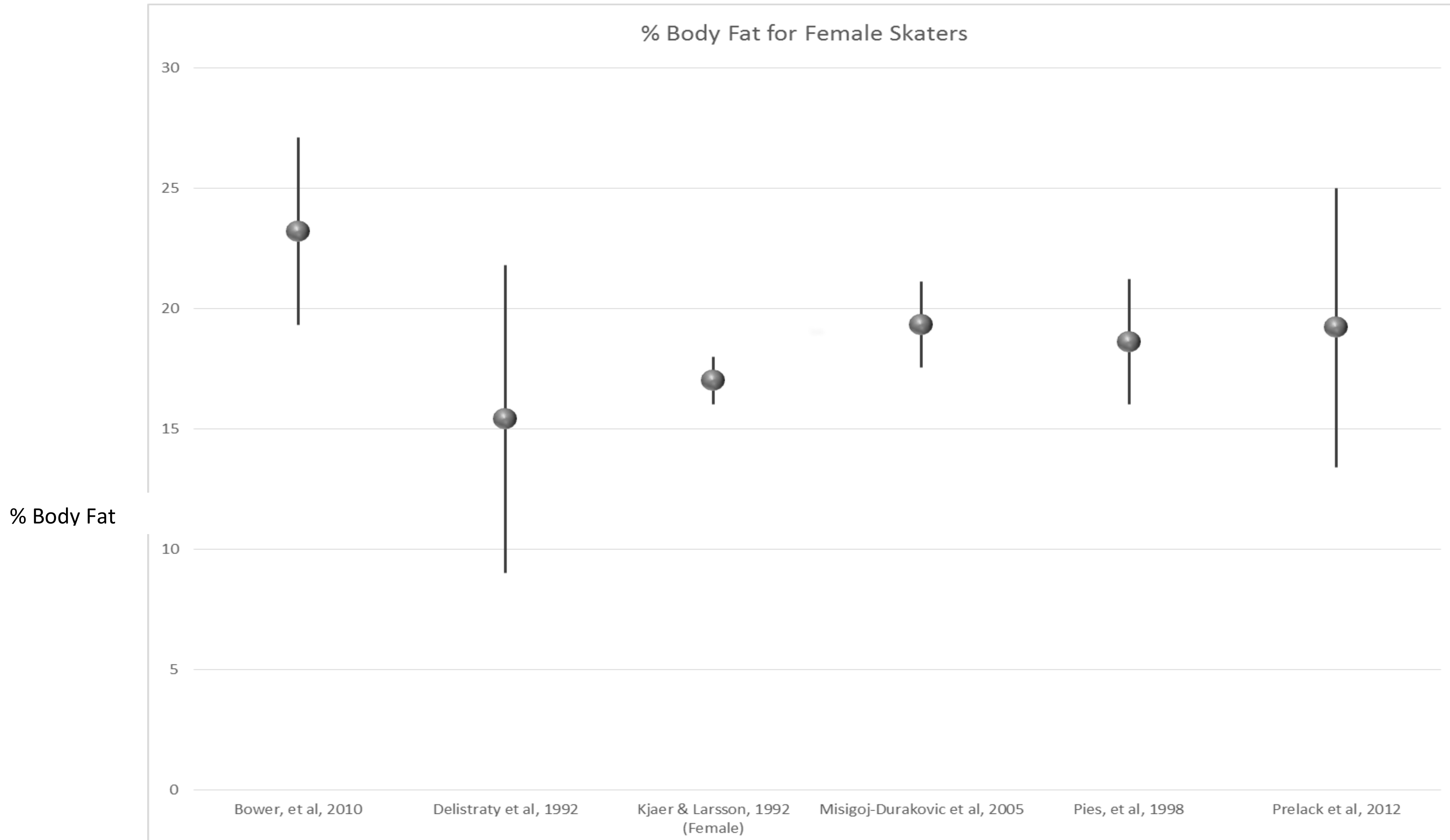


Figure 14: Percent Body Fat of Female Figure Skaters

3.3.3.5.2 Anthropometry Measurements

Though many studies took many skinfold measurements(Leone et al., 2002; Moison et al., 1991; Monsma & Malina, 2005; Monsma et al., 2006; Ross et al., 1977) , only 3 studies reported the somatotype proportions of competitive figure skaters (Monsma & Malina, 2005; Monsma et al., 2006; Ross et al., 1977). Calculations were done either using the Heath Carter method or unspecified.

Somototype	Somototype number	SD	Participant Characteristics/Study
Endomorphy	1.7	0.3	Sr. – Jr. Men, Ross et al. 1977
	2.6	0.7	Sr. – Jr. Women, Ross et al. 1977
	1.7	0.2	Novice Men, Ross et al. 1977
	2.1	0.4	Novice Women Men, Ross et al. 1977
	3.5	0.1	Test Stream, Monsma et al. 2005
	2.8	0.1	Pre-Elite, Monsma et al. 2005
	3.3	0.1	Elite, Monsma et al. 2005
	3.1	0.1	Freeskaters, Monsma et al. 2005
	3.4	0.1	Ice Dancers, Monsma et al. 2005
	3.0	0.1	Pairs, Monsma et al. 2005
	3.36	1.05	Monsma et al, 2006
Mesomoprphy	5.0	0.9	Sr. – Jr. Men, Ross et al. 1977
	3.8	0.6	Sr. – Jr. Women, Ross et al. 1977
	5.0	0.6	Novice. Men, Ross et al. 1977
	3.7	0.5	Novice Women Men, Ross et al. 1977
	3.7	0.1	Test Stream, Monsma et al. 2005
	3.4	0.1	Pre-Elite,, Monsma et al. 2005
	3.8	0.1	Elite,, Monsma et al. 2005
	2.9	0.1	Freeskaters, Monsma et al. 2005
	3.4	0.1	Ice Dancers, Monsma et al. 2005
	3.1	0.1	Pairs, Monsma et al. 2005
	3.70	0.86	Monsma et al, 2006
Ectomorphy	2.9	0.6	Sr. – Jr. Men, Ross et al. 1977
	3.0	0.9	Sr. – Jr. Women, Ross et al. 1977
	2.7	0.8	Novice Men, Ross et al. 1977
	3.9	0.5	Novice Women, Ross et al. 1977
	3.0	0.1	Test Stream, Monsma et al. 2005
	3.0	0.1	Pre-Elite, Monsma et al. 2005
	2.7	0.1	Elite, Monsma et al. 2005
	2.8	0.1	Freeskaters, Monsma et al. 2005
	3.7	0.1	Ice Dancers, Monsma et al. 2005
	3.0	0.1	Pairs, Monsma et al. 2005
	2.86	1.00	Monsma et al, 2006

Table 12: Table of Anthropometric Measurement from Studies involving Figure skaters

3.3.3.5.3 Bone Density

Two studies measured the bone density of competitive figure skaters at the elite level. Prelack et al., (2012) used dual X-ray absorptiometry (DXA) to measure the bone density of total body, spine, pelvis, and leg, while Olesen et al., (2002) used ultra sound to measure the calcaneus bone density skaters' heels.

3.3.3.5.4 Balance

The only skill-related fitness component that has been researched was balance in figure in skaters (Alpini et al., 2008; Kovacs et al., 2004; Saunders et al., 2013). These investigations used technology for assessing the balance or postural control of the skaters in lab settings. Both Saunders et al., (2012) and Kovacs et al., (2004) assessed postural control in skaters by measuring changes in the centre of pressure (CoP). All studies had very different investigation purposes, levels of skaters and disciplines. Alpini et al., (2008) used compare static postural control of synchronized skaters to a control group. Table 13 shows the investigations, the methods and tests used and the conclusions made by the investigators. This method studies vertical pressure fluctuations while the subject tries to maintain a stable stance on four independent force plates (Alpini et al., 2008).

Author	Testing Procedures and Equipment	Outcome Measures	Intervention Program	Conclusion
Alpini et al, 2008	Postural control measurements using posturography and specialized plates: standing balance on rigid pressure plate (eyes open and closed), and on 10cm foam covered pressure plate (eyes open and closed) for 32s Equipment: Force Plate : Tetrax by Sunlight, Israel)	**Posturography:** measures body sway through force plate measurement. **Stability:** as measure by the quotient of the sum of the body sway divided by body weight. Measured eyes open and closed and on firm surface and foam. **Weight distribution:** calculated by weight at each of the four sensors on pressure plate. Measured eyes open and closed and on firm surface and foam. **Fourier spectrum of sway**: mathematical analysis of wave signals produced by the subject's body oscillations required to maintain upright posture, subdivided into 8 frequency bands.	none	**Parameter stability** was higher than controls in all four tests conditions but not significant (p=0.10) **Weight distribution:** unexpectedly was higher (less postural control in skaters on the less challenging firm pressure plate conditions. But on more challenging 10cm foam padded plate conditions, skaters had lower WDI scores (better postural control). **Fourier spectrum of sway:** skaters had very low sway compared to control in low frequencies but was not significantly different in high and medium frequencies. Postural control in synchronized figure as a results from adaptations to the intense performance in an unusual environment and differs from controls both quantitatively and qualitatively.

Author	Testing Procedures and Equipment	Outcome Measures	Intervention Program	Conclusion
Kovacs et al, 2004	Centre of Pressure (CoP) path length with Force Plate during single leg balance test, and jump landing test with eyes closed Equipment: Force Plate : A(MTI model OR^ 6, Boston, MA)	CoP path length; CoP path area over 5 different tests: Single limb stance (eyes open and closed), landing jump test (eyes open and closed), and single limb stance with skate on (eyes open only)	4 week, 3X's 30 minute off ice training program	Off ice neuromuscular training improved postural control in figure skaters whereas basic exercise training did not The % improvement in the Neuromuscular trained group was significantly better (21 % +/- 22), than the basic exercise trained group (-4.9% +/- 24.9%), p<0.05 Magnitude of improvement in NMT ranged from 1%-21% depending on test
Saunders et al, 2012	EYES OPEN using force plate for 15 s : Single Leg Stance (SLS) and Single Leg Landing(SLL) Equipement: Berteck 4060-10 force plate (Bertec Corportation, Columbus, OH)	Balance testing: Single Leg Stance (SLS)- Single Leg Landing(SLL) - Time to Stabilization (TTS) CALCULATED: Time to Stabilization (TTS)	6 week neuromuscular training program	Both groups improved their scores (but the higher skilled group improved 25% more than the less skilled skaters. High level skaters improved to a great extent with higher level skaters rather than the low which was opposite to the hypothesis.

Table 13: Balance Investigation Characteristics

3.3.1.1 Interventions

Table 13 outlines the intervention studies of figure skaters. Only seven of the studies utilized interventions on figure skaters. The rest of the studies were cross sectional research.

Author	Outcome Measures	Intervention	Time	Types of Skaters	n
McMaster et al, 1979	VO2 max; Timed ½ mile skate	On Ice Interval Training to improve cardiovascular endurance	½ hour; 3X's /wk; 12 weeks	Preliminary to Eight Figure Test*	Not reported
Tornese et al, 2011	Vestibuloocular reflex and Visuovestibuloocular reflex	Use of virtual reality to improve balance reflexes in ice dancers	20 days	Elite Ice Dancers	5 (3F, 2M)
Kovacs et al, 2004	Measured with force plate	Off-Ice neuromuscular training program to compare to basic exercise program	½ hour; 3 days/wk; 4 weeks	Skaters of all disciplines and various levels' Intermediate through Senior and in STARskate*** program	44 F (22 skaters received interventi on' 22 control)
Saunders et al, 2013	Center of Pressure; Time to Stabilization measured with force plate	Off-Ice neuromuscular training program to determine if skill level of the skater influenced the effectiveness of the training program	½ hour; 3 days/wk; 6 weeks	Single Figure Skaters of various levels under elite	26 F

Author	Outcome Measures	Intervention	Time	Types of Skaters	n
Smith et al, 1991	Questionnaire regarding knee pain, flexibility and joint rotational measurements	Flexibility exercises and counselling to be done by the skater on their own time	Several months depending on skater and discipline (skaters tested and retested at different training camps	Elite Junior Figure Skaters	28 F
Mannix et al, 1996	VO_2 peak (l/min); VO_2 peak (ml/kg◦min); Work Rate at VO_2 peak (% predicted); Aerobic Threshold (% VO_2 peak); SupMax Time	Off-Ice Interval Training to improve cardiovascular endurance using cycle ergometer	33 in min, 4 days/wk for 10 wks at high intensity interval (5 min, 5 times with 2 min recovery)	Skaters at a skating training academy of various levels: Senior (n=2) Junior (n=1) Novice (n=9) Intermediate (n=3)	15 (12F, 3M)
***Skater level defined by Figure Tests which were eliminated from competition in 1994, ** Skater level defined by US Figure Skating, ***Skater level as defined by Skate Canada**					

Table 14: Intervention Investigation Characteristics

3.3.4 Injuries and Preventions

Table 14 refers to studies that collected data on the variety and nature of injuries sustained by figure skaters, though almost all were targeted mostly at elite skaters. The skating disciplines included were varied amongst the studies, and for some, within the studies. Only one study, (Dubravcic-Simunjak et al., 2006), reported injury rates for synchronized skaters and one study reported injuries in adult skaters (Ferrara & Hollingsworth, 2007). Several studies target certain types of injuries but no studies explicitly investigated the same injury. Comparisons of the studies of is unreliable since there is wide range of participants, types of injuries studied or reported, disciplines, proficiency levels, training conditions and methods of collecting or reporting data on the injuries. None of the studies regarding injuries in figure skaters reported any broken bones or injuries requiring surgery.

Types of Injuries Investigated	Studies	Method or Measures	Type of Skaters used in the Study	n
Common foot problems due to skating boots	Davis & Litman, 1979	Questionnaire	Not specified	45
All types of injuries experienced in career	Dubravcic-Simunjak, Kuipers, Moran, Simunjak, & Pecina, 2006	Questionnaire	Elite World Level Synchronized Skaters	528 (514F, 14M)
All types of injuries experienced in career	Dubravcic-Simunjak, Pecina, Kuipers, Moran, & Haspl, 2003	Questionnaire	Elite World Level Junior Skaters (Singles, Pairs and Ice Dancers)	469 (236F, 233M)
All types of injuries experienced	Ferrara & Hollingsworth, 2007	Questionnaire	Adult Figure Skaters	130 (113F, 17M)
All types of injuries experienced	Kjaer & Larsson, 1992	Record of injuries by physician over 1 year	Elite Level	8 (5F, 3M)
All types of injuries experienced over 9 months	Smith & Ludington, 1989	Questionnaire	Elite Pairs and Ice Dancers	48 (24 Teams)
All types of injuries experienced 1 year	Brock & Striowski, 1986	Questionnaire	Elite National	60
Low Back Pain	Kujala, 1997	Questionnaire	Unspecified	17F

Types of Injuries Investigated	Studies	Method or Measures	Type of Skaters used in the Study	n
Stress Fractures	Oleson et al., 2002	Questionnaire and Interview	Adolescent Competitive Figure Skaters	36F
Achilles Tendon	Perry, Tillett, Mitchell, Maffulli, & Morrissey, 2012	Questionnaire and ultrasound on Achilles tendon	Various levels and disciplines	20 (12F, 8M)
Stress Fractures	Pecina, Bohanic, & Dubravcic, 1990	Questionnaire	World Elite Level	42 (number of gender not specified)
Anterior Knee Pain	Smith et al., 1991	Physical Examination	Elite Junior Figure Skaters	46 F

Table 15: Studies on Injuries of Figure Skaters, the methods used and types of injuries investigated.

3.4 Discussion

Most of the research on figure skaters has been conducted in the past 10 years (50%) since the ISU brought in a new format to judging the sport based mostly on evidence based criteria. Changes to the rules have changed the demands on athletes participating in the sport. Female athletes tend to be younger and have shorter careers in the sport spanning on average only 1 Olympic year. Female Olympic medalist skaters attempting to compete over multiple Olympics have placed lower trying to retain their titles, such as Yuna Kim and Mao Asada losing out to younger skater. Male figure skaters have had to adapt to the physical demands of developing a triple axel and quadruple jumps. The new judging system has put more emphasis on technical jumps and increased the need for strength and flexibility for higher levels spins. Footwork sequences have dramatically changed based on what is required for increased levels and points; which are constantly changing in some aspect from year to year.

The history of figure skating has greatly influenced the nature of the figure skaters by changing the physical demands of the sport. Table 15 illustrates the number of studies executed during significant time periods of change within the sport of figure skating. No research was conducted prior to 1977 on figure skaters. Limited research on figure skaters have been repeated in any field. Only 36% of studies have been conducted recent enough compared to changes in rules that have altered the demands of the sport (Table 15).

Year of Publication	ISU changes to competition	Number of Articles and Percentage
< 1980	No research prior to 1977. All studies conducted after ISU changes competition to include a short program after 1972 to reduce the weight of figures and increase TV ratings.	3 (9%)
1980-1994	During this time, ISU changes increases weight of short program until it completely takes Figures out of competition in 1994	9 (27%)
1995-2004	2002 Salt Lake City Scandal involving pair teams and judging lead to creation of new Judging System called Cumulative Points System	9 (27%)
>2005	All skaters judged on new ISU Judging System with constant rule changes	12 (36%)

Table 16: Timeline of Studies by Significant Events

This review shows that there was no consistency in the level or proficiency of the skaters involved in the studies. Several studies reported levels of skaters based on skating tests passed, while others reported levels based on competition category or level. Even more ambiguous is that each country defines test levels and competition categories differently up until the expertise of Junior and Senior categories as defined by the ISU. An added complication is that there is an extreme amount of variety in national level skaters across different countries. Many studies did not even report levels of skating.

3.4.1 Injuries and Prevention

Studies regarding injuries to skaters involved the largest number of participants (n=1492), followed by studies of skaters and their physical fitness (n = 989). Only 10 skaters were used to related performance to equipment used by skaters (their skates) (Haguenauer et al., 2006). The majority of research conducted on figure skater injuries have been cross-sectional studies that utilize questionnaires to obtain injury information while some studies back up the information with medical records. As well, the majority of research on injuries have been done on elite skaters.

At least a few of the studies acknowledged a bias in the questionnaires that skaters may not actually recall all their injuries (Kjaer & Larsson, 1992; Smith & Ludington, 1989). Participants in the studies ranged from 8 elite singles skaters to 528 elite synchronized skaters.

Investigations into injury rates in figure skaters began in the 1980's while figures were still a critical part of the performance and required many hours of training. Brock & Striowski

(1986) conducted a study on elite figure skaters of singles, pairs and ice dancers and found that 46.6 % reported significant injuries with in a one year period. A much higher rate of in injury was reported in Smith et al (1989), where only elite pairs and ice dancers were questioned with 48 skaters reporting 49 different injuries in only 9 months. Dubravcic-Simunjak et al., (2003) who also questioned skaters who were ice dancers, pairs, and singles skaters reported an injury rate of 79.5%. Kjaer & Larsson (1990) found 75% of their Danish elite singles skaters had sustained an injury over the year period. Considering the difference in disciplines investigated in the studies, the lowest injury rate reported by Kjaer & Larsson (1990) of only singles skaters and the extremely high rate of injuries in Smith et al., (1989) which only included pairs and ice dancers suggest that partner disciplines experience more injuries than singles skaters. The median injury rates reported by Dubravcic-Simunjak et al.,(2003) and Brock and Striowski (1986) who questioned singles skaters, ice dancers and pair skaters support this. They also acknowledged that excluding the injuries sustained from overhead lifts, the injury rate was reduced to 67%.

Studies conflicted on whether acute injuries predominated overuse injuries most likely due to the different disciplines of figure skating being investigated and the length of time allowed for reporting an injury (9 months compared to a skating career). In Brock & Striowski (1986), 50% of injuries were acute while 42.9% were overuse injuries such as tendinitis, shin splints, and chrondromalacia patellae. They also noted that skaters who suffered acute injuries returned to ice sooner than the skaters who had suffered overuse injuries (12.2 days compared to 17.9 days). Kjaer & Larsson (1990) found 56% of the injuries experienced by the singles skaters were acute with most of them occurring on the ice.

Smith et al (1989) found 45% of the injuries sustained were acute while 55% of the injuries were overuse syndromes experienced by the 48 pair skaters and ice dancers. For synchronized skaters, the reported injury rate was 65.8% for overuse injuries reported by a female synchro skater in a career with only 34.2% of that occurring while the skater was on a team. Only 42.4% of the female skaters had suffered acute injuries in their career.

Overuse injuries include jumper's knee, stress fractures, shin splints, groin pain, ankle impingement, Achilles tendinitis, Osgood Schlatter disease, plantar fasciitis, hamstring syndrome. Overuse injuries include jumper's knee, stress fractures, shin splints, groin pain, ankle impingement, Achilles tendinitis, Osgood Schlatter disease, plantar fasciitis, hamstring syndrome. Among the acute injuries reported were sprains, lacerations, fractures, head injuries and dislocations. Pairs skaters and ice dancers have a higher risk of acute injury because of falls from lifts and throws (Dubravcic-Simunjak et al., 2003; Smith & Ludington, 1989), while synchronized skaters along with ice dancers and pairs have a higher risk of lacerations (Dubravcic-Simunjak et al., 2006).

Some common overuse injuries reported were patellofemoral pain in the knee, Osgood-Schlatter disease (Dubravcic-Simunjak et al., 2003; Ferrara & Hollingsworth, 2007; Kjaer & Larsson, 1992), Jumper's knee(Dubravcic-Simunjak et al., 2003; Ferrara & Hollingsworth, 2007; Kjaer & Larsson, 1992), knee or ankle sprain (Dubravcic-Simunjak et al., 2006; Sandra Dubravcic-Simunjak et al., 2003; Kjaer & Larsson, 1992). Of the overuse injuries, stress fractures are the most common (Dubravcic-Simunjak et al., 2003).

Pecina et al., (1990) questioned elite world class skaters regarding stress fractures specifically and found that 21% reported stress fractures. The skaters did not present symptoms of stress fractures until 6-15 years after beginning intense training of 3-8 hours, 6 times per week. Of the stress fractures, four of them had occurred during preseason training just after adjustments had been made to increase the intensity. The five other fractures occurred during the regular training season and were on the take-off leg which is consistent with Oleson et al., (2002) who also found the majority of stress fractures occurred on the axel take-off leg in comparison to the landing foot. Of the stress fractures detected in Pecina et al, 1990, the on-ice occurring fractures of the anterior cortex of the mid-third of the tibia were most likely a result of the tensile forces associated with jumping. They were also a very small percentage of the stress fractures.

Smith et al (1991) found that 33% of elite Junior level skater suffered from anterior knee pain. In a comparable study, Dubravcic-Semunjak et al., (2003) found approximately 255 of elite Junior level skaters suffered from acute injuries while almost half of them had reported overuse injuries. The majority of skaters' injuries are found in the lower extremities (S Dubravcic-Simunjak et al., 2006; Dubravcic-Simunjak et al., 2003; Ferrara & Hollingsworth, 2007; Oleson et al., 2002; Pecina et al., 1990; Smith & Ludington, 1989).

Lower back pain is an injury reported by many figure skaters (Dubravcic-Simunjak et al., 2006; Dubravcic-Simunjak et al., 2003; Kujala, Taimela, Erkintalo, Salminen, & Kaprio, 1996; Kujala, 1997). Kujala et al., (1997) showed that female athletes with lower maximal lumbar extension and lower lumbar ROM had a higher risk of developing lower back pain. They also suggested that there may be a correlation between the onset of lower back pain and peak growth velocity and that repetitive extension maneuvers may structurally affect the lumbar spine. Low back pain in figure skaters reported by synchro skaters was 13.4% female and 14.3 % male (Dubravcic-Simunjak et al., 2006)

Perry et al., (2002) was the only study to investigate the Achilles tendon morphology in figure skaters. They were unable to detect any signs of hypoechoic areas, neovascularization, paratenon blurruing or focal thickening (tendinopathy symptoms). However, they did record that the middle portion of the Achilles tendons of figure skaters was significantly thicker than those of the controls and that postulated that this might be a result of a training adaptations (Perry et al., 2012).

The only study of adult figure skaters (Ferrara & Hollingsworth, 2007) showed adult skaters increase their risk of injury and impair their athletic performance because they have very poor warm up and training habits. Smith et al., (1991) found similar results in that skaters who improved their hamstring and quadriceps flexibility reduced or eliminated their knee pain and that hamstring flexibility was correlated with patellofemoral pain.

In Brock and Striowski (1986), there was no correlation between skating experience, height, weight, or % body fat and injuries, but 17.9% of injuries were thought to be related to the skaters' boots, and 14.3 % of injuries related to the ice conditions. Most of the injuries occurred during a program run through or by practicing parts of the program. None of the skaters in Brock & Striowski (1986) reported having more than one significant injury in one year while it was common in Smith et al., (1989) for the female skaters who had a partner to suffer from more than one serious injury within a month. In Brock & Striowski (1986), 28.6% of the injuries occurred during jumps and 21.4% occurred during other parts of program. Dubravcic et al., (2005) reported that the 82% of the acute injuries to synchro skaters occurred during on ice practice while on 18% happened during the off ice training. The majority of these injuries (73.1%) occurred practicing team elements compared to the 26.9% that occurred practicing individual elements.

Injury rates in figure skating are still considered quite low. Incidence of injuries as 1.37 per 1000 hrs of total training or 1.72 per 1000 hr on ice training (Kjaer & Larsson, 1992) for singles skaters. (Brock & Striowski, 1986) investigated injuries among elite skaters and found the incidence of injury rate to be 3 per 100 hr of total training. In comparison, the Canadian skaters spent only 12 min a week no warming up and stretching compared to the 75 min per week in the Kjaer study. Ferrera (2007) could not directly relate the lack of warm up or stretching directly to injury rates for adult skaters. However, improved flexibility of thigh muscles was related to decreased incidence of anterior knee pain (Smith et al., 1991).

Only one study investigated risks of injury of younger skaters in relation to bone density and the prevention of stress fractures. Olesen et al., (2002) showed that the benefits of increased bone density in figure skaters were related to their skill level and training history in that skaters who mastered an axel at a younger age (mean 9.8 years), and consequently began working on their double jumps, were less likely to obtain a stress fracture despite having the same acquired bone density compared to skater who did master their axel until around 11.5 years of age.

Ferrara (2007) also found no difference in the number of training hours spent skating for the adult skaters whom had sustained a skating related injury compared to those who had not.

3.4.2 Physical Characteristics

Physical characteristics such as age and health and skill-related fitness components are summarized.

3.4.2.1 Age

Ages of figure skaters researched depended on the skaters' level, and the purpose of the study. The youngest groups of skaters (mean age 10.92 yrs (Misigoj-Durakovic et al., 2005) were investigated for their premenarchal status, while the oldest skaters, other than the adult skaters, were elite male skaters who were around the age of 23 and at the pinnacle of their careers, (Fortin & Roberts, 2003).

3.4.3 Health-Related Physical Fitness

All components of health-related physical fitness have been investigated in figure skaters at some point. Comparisons of the data is not possible because there have been only a few of the physical fitness components have been repeated and most of the tests have been done on skaters that are not comparable in terms of skating discipline or level.

3.4.3.1 Body Composition

Body compositions was measured using a variety of methods including anthropometric measures and bone density.

3.4.3.1.1 Anthropometry

Studies such as the one conducted by Ross et al in 1977 regarding somatotype are almost obsolete. Ross et al acknowledged then that successful figure skaters were more endomorphic with age but that it was more beneficial to be mesomorphic. "Although this disadvantage of is offset by increasing experience which will be reflected in greater consistency and poise in performing school figures and in enhanced artistic impression for free skating, female free skaters with competitive aspirations should probably be well advanced towards mastering the difficult jumps before the change towards endomorphy occurs in their physical development"(Ross et al., 1977). Since the removal of figures from competition in 1994, maturity obtained from hours of training figures has diminished as can be seen by the younger ages of competitors and medalists at the Olympic and World levels.

3.4.3.1.2 Bone Density

Olesen et al., (2002) found no significant difference between their control group and skaters that had experienced a stress fracture. Skaters without a history of stress fractures had significantly more BMD (15% more to skaters with a stress fracture, 17 % more than controls) in both heels. The BMD of the landing foot was 6.8% greater than other foot. Triple jumpers also showed greater BMD (14%) than skaters who could double jumps but not triples. In terms of ages of skaters or when they started competitive skating, there was no significant difference for development of BMD. However, the researchers did find that skaters in the stress fracture group has mastered their axel and began training double jumps at an older age of 11.5 years compared to the group who had not developed stress fractures who mastered their axel and trained their double jumps before age 10. Prelack et al., (2012) compared BMD of skaters from different disciplines and found that singles had higher BMD in the legs, pelvis and total body than ice dancers and pair skaters and also pair skaters had higher BMD in the pelvis compared to the ice dancers.

3.4.3.2 Flexibility

A high level of flexibility is a crucially important in figure skating yet has been barely researched. Kujala (1997) and Smith et al., (1991) showed that increases in flexibility reduce pain and can prevent injuries. Ferrara & Hollingsworth (2007) stated the need for adult skaters to be educated in proper warm ups and stretching. Leone et al., (2002) was the only study to perform a basic flexibility test of figure skaters using the Sit and Reach Test.

3.4.3.3 Muscular Strength and Muscular Endurance

All skating disciplines require strength for the execution of different skills (Bower et al., 2010; Comuk & Erden, 2012; Delistraty et al., 1992; King, 2005; McMaster et al., 1979; Peltonen et al., 1998; Pies et al., 1998; Podolsky et al., 1990) and the prevention of injuries (Abbott & Hecht, 2013; Dubravcic-Simunjak et al., 2003; Kujala, 1997; Porter, 2013). Comuk & Erden (2012) investigated strength and endurance parameters in skaters and compared those skaters who could successfully perform a double axel to those that could not. In this study the double axel skaters performed better than their counterparts in tests of the 12-Minute Run/Walk for cardiovascular endurance, the 1 Minute Modified Push-Ups, and the Biering-Sorensen muscular endurance tests as well as showing more strength in the knees and ankles-especially in their take-off legs.

Bower et al., (2010) showed that vertical jump performance could be used to predict on ice speed and acceleration in elite level synchronized skaters. Vertical jump was tested by Delistraty et al., (1992) on younger skaters (mean age <14) but did not record their level of skating proficiency so that this data is not useful for any skaters, coaches, or parents. Podolsky et al., (1990) looked at biomechanics of figure skaters related to their jump height. Sands et al (2012) looked at off ice repeated jumps of nationally ranked pair skaters and could predict approximately 50% of the competitive rankings based on the power index generated from their tests. Many studies have investigated vertical jumps in figure skaters but none of them have related these measures to on-ice performance of jumps.

3.4.4 Skill-Related Physical Fitness

Very little research has been done in the areas of skill related fitness such speed, agility and coordination. Only balance and power in terms of vertical jump have been investigated in figure skaters.

3.4.4.1 Balance

Balance investigations in figure skaters have been confined to laboratory tests and have not been related to any on ice performance of skaters of any level, proficiency or discipline. Despite the lack of connection, studies specific to figure skaters have concluded that off-ice conditioning programs emphasizing balance and ankle stability should be incorporated into the normal training programs of skaters (Dubravcic-Simunjak et al., 2003; Saunders et al., 2013).

3.4.5 Interventions

Both studies regarding interventions with health-related physical fitness of aerobic endurance were done while figures were still part of competitive competition (Mannix et al., 1996; McMaster et al., 1979). Both studies looked at improving cardiovascular endurance through off-ice and on-ice training measures respectively. Because of figures having a considerable contribution to the athletes scores, this was a time when the endurance demands of a competitive figure skater were not as important as they are currently are in the new judging system. Yet no studies have investigated the cardiovascular demands of a figure skater as they stand presently.

3.5 Conclusion

The majority of research in figure skater has been centered on elite athletes in the age ranges of 15-19 years of age. While young developmental figure skaters under the age of 14 make up more than 50% of the figure skating population in Canada (Skate Canada, 2013), research in involving this age and level of skating is virtually negligible. Skill-related physical fitness has been under researched with the exception of balance in figure skaters. Though health-related physical fitness has been researched, there is practically no evidence to link to the performance of the figure skaters and their skills. Injuries to figure skaters have been the most researched though all the studies reflected on current skaters using questionnaires and recall of injuries. No studies were done over time to include skaters that may have left the sport due to injuries. More research is needed on the physical fitness and especially skill-related fitness of skaters who make up the major population of participation in the sport, mainly skaters under the age of 14 and who continually developing within the sport.

Research in this area could relay information as why injuries occur and as to why few skaters ever make it to the elite levels of the sport.

CHAPTER FOUR

4.1 Introduction

Physical fitness is defined as a set of attributes that are wither health- or skill-related and the degree to which people have these attributes can be measure with particular tests (Caspersen et al., 1985). Physical fitness is associated with many health benefits including improvement in cardiovascular health, bone health, and mental health (Carter & Micheli, 2011; Dumith et al., 2010) related to physical activity. Physical activity is defined as any body movement that is produced by the skeletal muscles that results in energy expenditure (Caspersen et al., 1985). The American College of Sports Medicine first established physical activity guidelines for children in 1988 with the goals of optimizing bone health, muscular strength, flexibility and general health (Carter & Micheli, 2011). Current physical activity guidelines for children recommend 60 minutes of vigorous activity per day (Canadian Society for Exercise Physiology, 2012; Carter & Micheli, 2011) . J*ust as the amount of physical activity ranges from low to high, so does the level of physical fitness (Caspersen et al., 1985).*

The health- and skill-related components of physical fitness are illustrated in figure 9. Health-related components are (a) cardiorespiratory endurance, (b) muscular endurance, (c) muscular strength, (d) body composition, and (e) flexibility. Skill-related components are (a) agility, (b) balance, (c) coordination, (d) speed, (e) power, and (f) reaction time. These components are defined later in this chapter. The five health-related components are not interrelated, for example, a person possess significant strength but lack flexibility. Health-related components of physical fitness are more vital to one's overall health than the components associated with athletic ability (Caspersen et al., 1985).

Off-ice performance measures that utilize assessments of both skill-related and health-related components of physical fitness are employed increasingly in the evaluation of figure skaters. However, there is little empirical evidence demonstrating the relationship between off-ice performance measures to the various skills performed on-ice in figure skating. Therefore, the purpose of this investigation was to examine the relationship between off-ice assessment measures and on-ice performance of select skills in young figure skaters. Twenty eight developmental figure skaters were evaluated for health-related and skill-related physical fitness, including measures of agility, balance, flexibility, and musculoskeletal strength and endurance. These measures were examined in relation to on-ice performance measurements for speed, as well as key figure skating elements (axel jump, back spin, and sit spin). The goal was to ascertain whether there was a relationship between off-ice fitness and on-ice performance of certain skills in figure skating. The findings of the study shall be useful for coaches and other stakeholders in developing better training programs for future figure skaters.

4.2 Study Design

The research utilized a cross sectional experimental design.

4.3 Participants

Twenty eight figure skaters from the Lower Mainland British Columbia and Vancouver Island were invited to and recruited to participate in the investigation by contact through their respective skating clubs, coaches and via figure skating websites. Female figure skaters between the ages of 6 and 14 were recruited if they compete currently in the STAR 2, STAR 3, STAR 4, or STAR 5 categories as outlined by the BC Section Competition criteria (part of the Learn To Train Stage of the Skate Canada Long Term Athlete Development Model). STAR 2 skaters will not be able to perform an axel or a sit spin well while STAR 5 skaters should be proficient at both.

For statistical analysis, skaters were grouped based on their ability to perform the required skills, for example those who could successfully perform an axel were compared to those who could not successfully complete one. Statistical analysis was not be based on category of skating or age due to the overlap of skating proficiency of each level.

4.4 Procedures

Data collection took place over two days of testing (one day for the Lower Mainland Group and one day for the Vancouver Island group). Each group had one day of testing consisting of two sessions separated by a half hour break referred to in Table 16 for a total time of 2.5 hours to complete all tests. Administering all assessments across one day is consistent with procedures for the US Figure Skating Association's STAR testing combine, which administers 15 different physical tests, in addition to the collection of anthropometric measurements for each skater. It is also consistent with other fitness testing protocols for children (Haga, 2008) which performed 8 tests, three of them consisting of endurance tests. For each skater, there will be a total of 1 hour of off-ice testing of physical fitness and one half hour of on ice-performance assessments for a total of less than 1.5 hours of light to moderate physical activity over 2.5 hours. This does not exceed what is accepted as a normal training session for a developmental figure skater at the learn to train stage of development (Skate Canada, 2010).

The smaller Vancouver Island group had a slightly modified testing schedule which does around their normal training session as they had a small number and extra ice for testing was not available.

Approximation of Time	Section 1	Section 2	Section 3	Section 4
1:00pm	Begin Off Ice Testing Protocols (1st half)			
1:30pm	Break	Begin Off Ice Testing Protocols (1st half)		
2:00 pm	Continue Off Ice Testing Protocols	Break	Begin Off Ice Testing Protocols (1st half)	
2:30 pm	Break	Continue Off Ice Testing Protocols	Break	Begin Off Ice Testing Protocols (1st half)
3:00 pm	Begin On Ice Testing	Break	Continue Off Ice Testing Protocols	Break
3:30pm		Begin On Ice Testing	Break	Continue Off Ice Testing Protocols
4:00pm			Begin On Ice Testing	Break
4:30pm				Begin On Ice Testing

Table 17: Schematic of Process of Testing Groups

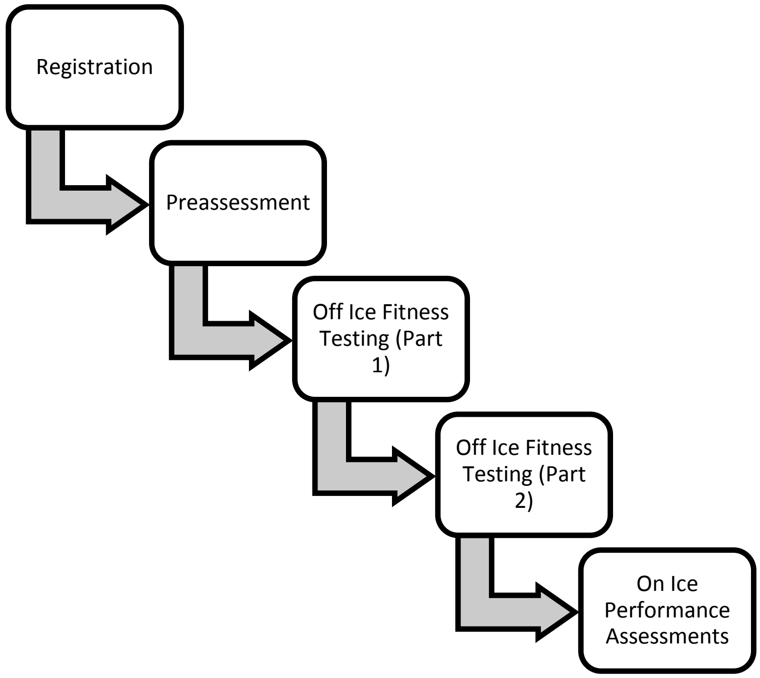


Figure 15: Procedure Schematic for Collecting Data, Fitness Test Results and Performance Assessments

Testing procedures were carried out by a team of qualified personnel (Skate Canada coaches with a University background) and were consistent for each test. On ice testing occurred in the order outlined in Figure 17. Skaters will be allowed to warm up on the ice for 5 minutes prior to testing and evaluation. Skaters were separated into sections for testing for efficiency and proceeded through the testing protocols as outlined in Figure 15.

4.4.1Pre-Assessment

Informed consent from parents and assent from children participants were be obtained upon arrival and check-in for the study (see Appendix B) as well as by email ahead of time. A health questionnaire was also be filled out by the participants' parents to ensure they are healthy to participate in the study. Birth date was recorded. In addition, information was collected for age of skating start and number of hours per week of training (skating and/or other activities outside of school) (see Appendix C) as possible confounds to the data if required. A Health Questionnaire was collected prior to testing during registration or before (Appendix D).

4.4.2 Off-Ice Fitness Testing Measurement

Skaters were warmed up by a qualified coach prior to testing. Skaters then proceeded through the testing protocols outlined in Figure 16. Skaters proceeded through the off-ice testing protocols in groups of approximately 5 -6 skaters providing recovery time while the other skaters of the group were being tested.

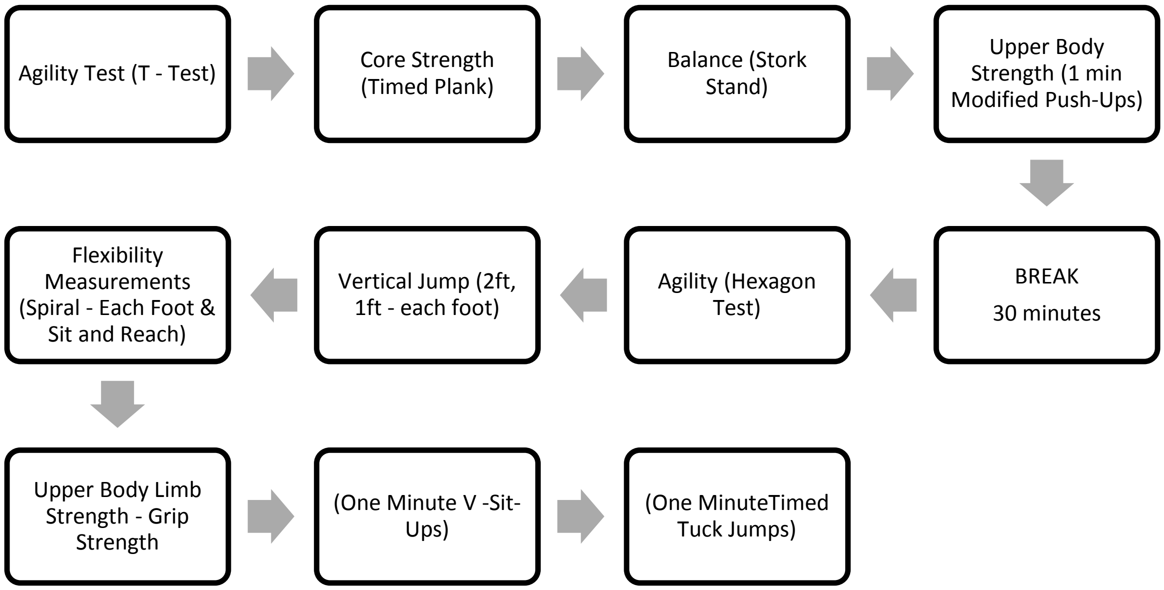


Figure 16: Schematic of Off-Ice Testing Protocols to be used

4.4.3 On-Ice Performance Assessments

The on-ice testing (Figure 17) commenced with the single lap speed test after the skaters had 5 minutes to do their on ice warm up and get used to the ice. The testing of elements began with the three spins, the sit spin and camel, followed by the back spin. The evaluation of the axel occurred last to minimize the effect of nervousness. As well, skaters will had the option of repeating any of the elements up to a maximum of 3 times though no participant in the study required that many attempts. Only the best performance was used for analysis. Evaluation of the elements was determined by a team of three qualified judges as a consensus during the Lower Mainland Testing. Only one judge was required for the Vancouver Island Testing Day due to much smaller numbers and lack of available judges.

Figure 17: Schematic of on-ice testing procedures

4.5 Assessments

An assessment battery will be administered consisting of both on-ice and off-ice measures. The off-ice testing measures assessed the health-related physical fitness and skill-related physical fitness of the figure skaters. The on-ice assessments will tested performance of specific figure skating skills (axel, sit spin, and backspin) that are crucial components of development, as well as on ice speed to quantify the skater's basic skating skill.

A total of ten off-ice assessments will be administered, which includes skill-related physical fitness tests of agility (T Test, Hexagon Test), and balance (Stork Stand); as well as health-related physical fitness tests, including: flexibility (Seated Reach), muscular strength (vertical jump and hand grip strength), muscular endurance (the One Minute Sit-Ups, One Minute Modified Push-Ups, the Plank), and power (the Timed Tuck Jumps). Some assessments that have were included are tests utilized by the US Figure Skating Association's STARS program (US Figure Skating Association, 2013) which were based on standards and protocols from *Essentials of Strength Training and Conditioning, 3rd ed* (US Figure Skating Association, n.d.). Additional tests include the One Minute Modified Push-Ups Test because it has been utilized by other researchers (Comuk & Erden, 2012), and the assessment of hand grip strength has been added to the test battery as a basic health-related physical fitness component of upper body muscular strength (Caspersen et al., 1985; Dumith et al., 2010).

4.5.1 Health Related Physical Fitness

As a basis for skating and other related sport activities, the following protocols were chosen to ascertain the basic health related physical fitness of the developmental figure skaters. The majority of protocols were chosen to allow for comparisons to other studies and that could be utilized in the future by coaches and parents because of the simplicity of the tests regarding minimal equipment and their ability for duplication.

4.5.1.1 Muscular Strength

Muscular strength was assessed using the hand grip strength for upper body strength and the vertical jump test for lower body strength and explosive power.

4.5.1.1.1 Hand Grip

A test of hand grip strength will be conducted using a dynamometer by Almedic, (Quebec City, Quebec). The test of the handgrip strength was performed on both hands. While standing, the athlete was instructed to hold the arms at their side, not touching their body. The athlete then held the dynamometer in the hand to be tested, with the arm at a right angle and the elbow by the side of the body. The handle of the dynamometer was adjusted if required so that the base could rest on first metacarpal (heel of palm), while the handle should rest on middle of four fingers. When ready the athlete was instructed to squeeze the dynamometer with maximum effort for 5 seconds. Up to three trials were made with a pause of about 10-20 seconds between each trial to avoid the effects of muscle fatigue. No other body movements were permitted. The results of the three trials were recorded with the results of each trial to the nearest kilogram.

Figure 18: Almedic Hand Grip Dynamometer

4.5.1.1.2 Vertical Jump

Vertical jump height is essential to all jumping movements in figure skating (Bower et al., 2010; Comuk & Erden, 2012; Delistraty et al., 1992) and were examined according to the protocol set out by the US STARS program (US Figure Skating Association, 2013) which uses standardized procedures. A coloured marker was used to mark the middle finger of the skater who was then instructed to mark the wall by reaching directly over their head. This is was recorded as standing height.

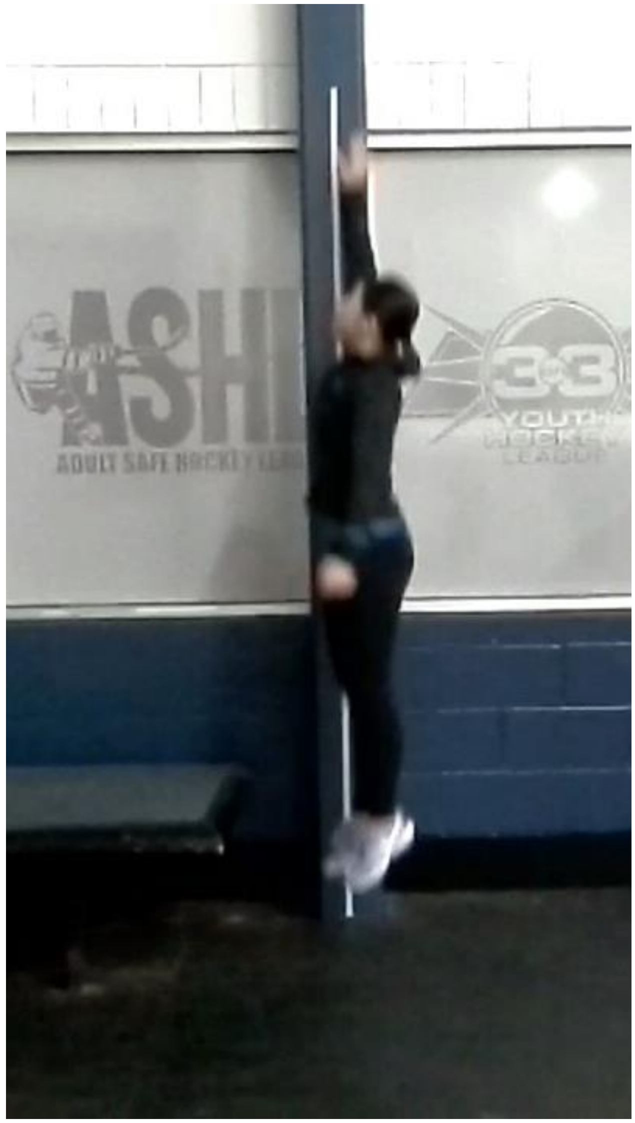


Figure 19: Skater performing Vertical Jump Test

The skater was then asked to jump as high as possible to mark the wall with the same middle finger. The difference in vertical height of the two marks was recorded as the vertical jump distance. Each skater was allowed three trials and the highest value was utilized for data analysis (US Figure Skating Association, 2013). The skater was then asked to repeat the test jumping from the right foot only, and then the left only. All vertical jump height tests were repeated with skates on after completion of the on ice evaluations.

4.5.1.2 Muscular Endurance Assessments

Muscular endurance was assessed using the timed tuck jumps for lower body explosive power endurance. Core muscular endurance was assessed by a combination of static and dynamic tests comprised of the plank test and one-minute sit-ups test. Upper body muscular endurance was assessed using the one minute modified push-ups test.

4.5.1.2.1 Timed Tuck Jumps

Timed tuck jumps represent a movement similar to combination jumps performed on the ice. The purpose of the assessment was to examine skater's capability to consistently and quickly jump up and down to a marked height within a one-minute time frame. The protocols used were the same as the STARS program (US Figure Skating Association, 2013). A mark was placed on the wall to the side of the skater and directly behind the skater in relation to the assessor. The mark was placed just above the height of the knee. The athlete tried to successfully complete as many tuck jumps with their knees at the bent 90° standing position height (level that mark is placed) within the time frame (30 seconds). Only jumps that were equal to or higher than the mark were count. The total number of jumps completed was recorded (US Figure Skating Association, 2013)

Figure 20: Skater performing Timed Tuck Jump Test

4.5.1.2.2 Core Strength Plank

Core strength and body alignment are important to all movements in figure skating – spins, jumps, footwork, changes of direction, and edge balance (US Figure Skating Association, 2013). The side plank is an oblique (side) abdominal strength exercise involving balance and proper body alignment of the shoulders, spine, and hips. The length of time the skater could maintain and hold a sideways plank position in both directions was recorded to

2

Figure 21: Skater performing Side Plank Test

4.5.1.2.3 One Minute Sit-Ups Test

Core strength and balance are critical to all movements in figure skating – spins, jumps, footwork, changes in direction, and edge balance (US Figure Skating Association, 2013).Core strength comes from the abdominal muscles. The purpose of this assessment was to measure the endurance of the abdominal muscles. The following procedures were adapted from *ACSM's Foundations of Strength Training and Conditioning*. The One-Minute Sit-Up variation was chosen because it is more appropriate for children and is also used by the US Figure Skating Association for assessing figure skaters. The skater was asked to lie in the prone position on a mat with both knees bent at right angles and both feet shoulder width apart. Both arms lied flat on the thighs. The skaters then completed the sit up by tucking their chin into their chest and lifting their body, sliding their hands up to their knees, then returning to the starting position with the shoulder blades on the mat. The skater was instructed to perform as many sit-ups as possible within one minute. The total number of sit ups was recorded (Comuk & Erden, 2012; US Figure Skating Association, 2013).

Figure 22: Skater Performing Sit Up Test

4.5.1.2.4 One Minute Modified Push-Ups Test

In figure skating, arm strength and shoulder stability are important for rotational control on entry and on landings of spins and jumps (US Figure Skating Association, 2013). The purpose of this assessment was to measure the musculoskeletal endurance of the shoulder, chest, and triceps' muscles. The following procedures were adapted from *ACSM's Foundations of Strength Training and Conditioning*. The One-Minute Modified Push-Up variation was chosen because it is more appropriate for children. The skater was then asked to lay in a prone position on a mat with both legs together. The skaters' hands were placed under the shoulders pointing forward with knees bent. Skaters' pushed up from the mat by straightening their elbows and keeping knees planted on the mat and the upper body in a straight line. The skaters return to the starting position to complete one push up.

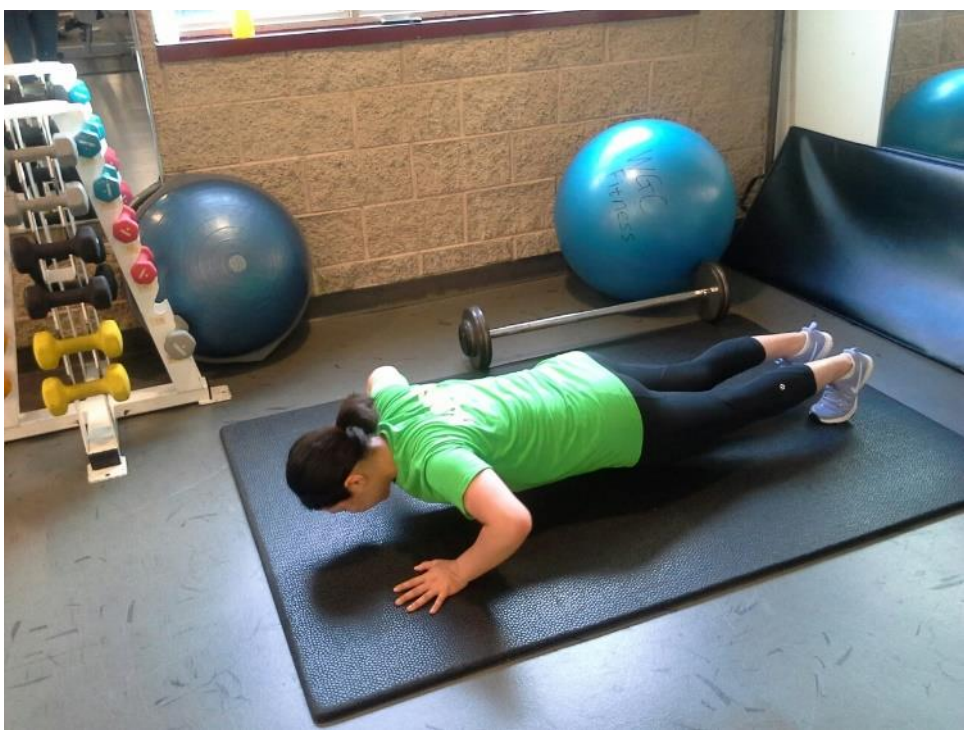


Figure 23: Skater performing Push-Up Test

The skaters' performed as many push-ups as possible within one minute. The total number of push ups was recorded (Comuk & Erden, 2012). However, results were not directly comparable to the US STARS program as they employ the number of push ups until exhaustion procedure.

4.5.1.3 Flexibility

Flexibility refers to the range of movement in a joint or series of joints, and lengthening and shortening in the muscles that cross these joints to induce a bending movement or motion (Caspersen et al., 1985). In figure skating a high level of flexibility is required for achieving difficult spin positions and variations.

4.5.1.3.1 Seated Reach

The seated reach is an assessment that examines flexibility within the postural spine muscles, lower back, gluteus, and leg muscles and is directly related to the sit spin and other difficult positions in skating that represent greater point values. The following procedures were adapted and modified from *ACSM's Foundations of Strength Training and Conditioning* and is also used by the US Figure Skating Association for assessing figure skaters. Skaters were asked to sit on the floor with legs fully extended in front of the body and slightly apart with toes pointed upward. A baseline will be made by connecting both heels along the ground as shown in Figure 24. Upon taking a deep breath, skaters were instructed to reach forward along the ground with both hands between the legs as shown in Figure 24 and past the feet as far as possible on the exhale. The distance reached by the fingers past the baseline of the foot was recorded.

Figure 24: Skater performing Seated Reach Test

4.5.1.3.2 Standing Spirals

The standing spiral is almost identical to the same stretch position used in the on-ice spiral, which is used in both spiral and camel spins. The skaters were assessed for both legs and may perform the spiral alongside a wall to steady them for balance but were not permitted to support his or her own weight using the wall at any time. The height of the supporting leg and the height of the free leg to the toe were recorded and a calculation was to determine the degree of flexibility from the base line.

NOTE: Due to an error in the recording of the height of the free leg of the tester for all skaters, the standing spiral assessment was removed from data analysis.

Figure 25: Skater performing Standing Spiral Test

4.5.2. Skill Related Physical Fitness

The selected protocols below were chosen to ascertain the skill-related fitness of the developmental figure skaters.

4.5.2.1 Aility

Agility is a measure of skill-related physical fitness and refers to an individual's capability to rapidly change body position or direction. In figure skating, a skater must be able to change direction and rotation very quickly. To examine these requirements two different tests of agility will be administered: the Hexagon Jump and the T-test. The Hexagon Jump test is included to assess the athlete's capability to make rapid movements, and change in direction, while maintaining core balance. The purpose of the T-test is to assess one's capability to maintain quickness and core balance while rapidly changing direction (forwards, backwards, and laterally), all of which are required for the successful performance of footwork, stopping, and changing of direction with momentum and control on the ice (US Figure Skating Association, 2013). Rapid movements, change in direction, and core balance are all critical for the performance of figure skating jumps, spins, and footwork skills (US Figure Skating Association, 2013).

4.5.2.1.1 Hexagon Jump

The Hexagon jump is a test of speed for jumping in, out, and around each of the sides of a marked hexagon in a continuous clockwise direction for a total of 18 two-footed jumps (three complete cycles). The following procedures were adapted from *ACSM's Foundations of Strength Training and Conditioning* and is also used by the US Figure Skating Association for assessing figure skaters. The goal was to complete cleanly all 18 jumps in the fastest time possible.

To administer the test, a hexagon (six sided shape) was pre-marked on the floor with tape. The length of each side was 60.5 cm (24 inches), and each angle was 120 degrees (Figure 26). Athletes began by standing comfortably on both feet, just inside the hexagon, with their hands on their hips. On the ‘go’ command, the athlete jumped ahead across the line, then back over the same line into the middle of the hexagon. All jumps were two foot jumps. They then jumped over the next side and back into the hexagon, continuing to face forward with feet together. The athlete continued as per this format over each consecutive line until completing three revolutions. Time was stopped after the completion of 3 revolutions. The best time in seconds of two trials was used for analysis. The test was performed in both the clockwise and counter-clockwise direction.

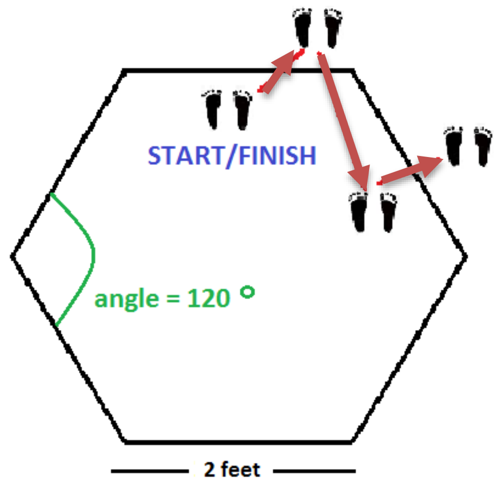


Figure 26: Set-Up and Direction for the Hexagon Jump

4.5.2.1.2 T-Test

The T-test, a standardized test implemented in a variety of sport testing (Wood, 2001), involves running forward, shuffling sideways, and running backward). The following procedures were adapted from *ACSM's Foundations of Strength Training and Conditioning* and is also used by the US Figure Skating Association for assessing figure skaters. To administer the assessment, four cones were placed in the shape of a 'T' using the distances of 10 yards for each direction (5 yards = 4.57 m, 10 yards = 9.14 m) (Figure 27).

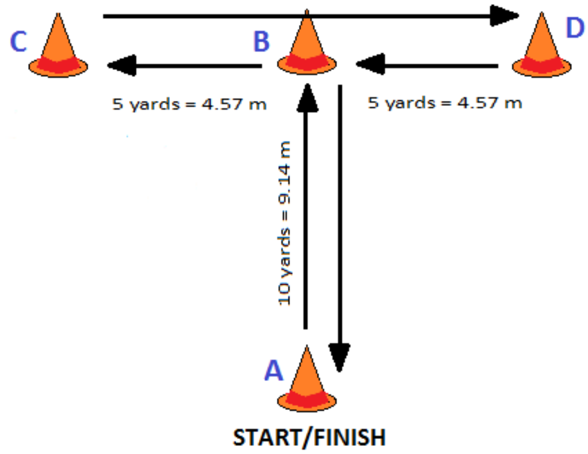


Figure 27: Set-Up for T - Test

Starting at cone A, the athlete was instructed to sprint as quickly as possible to cone B, touching the base of the cone with his or her right hand. The athlete then turned left and shuffle sideways to cone C, touching the base with the left hand, then shuffled sideways to the right to cone D, touching the base with the right hand. The athlete then shuffled back to cone B, touching the base with the left hand, and then rzn backwards to cone A. The time was stopped as the athlete passed cone A and recorded in seconds.

4.5.2.2 Balance

Balance is essential to the sport of figure skating for all disciplines because skaters have to be able to balance on their blades while turning, spinning, and gliding (US Figure Skating Association, 2013). This was the first study to utilize a basic balance assessment

4.5.2.2.1 Stork Stand

The following procedures were adapted from *ACSM's Foundations of Strength Training and Conditioning* and are also used by the US Figure Skating Association for assessing figure skaters. The athletes were instructed to stand without shoes on and with the hands above the head. Specifically, the athletes were asked to stand on one foot with the other foot placed precisely on the inside of the standing knee (making a "4" or "P" position) (Figure 27). Results from four trials were collected. In the first two trials, the skaters were instructed to keep their eyes open while standing in the position for as long as possible to a maximum duration of 120 seconds. Data will be collected for both the dominant leg and the non-dominant leg, beginning with the dominant leg. In the final two trials, the skater were instructed to stand with eyes closed, also holding the position as long as possible to a maximum time duration of 120 seconds, completing one trial per leg, beginning with dominant leg.

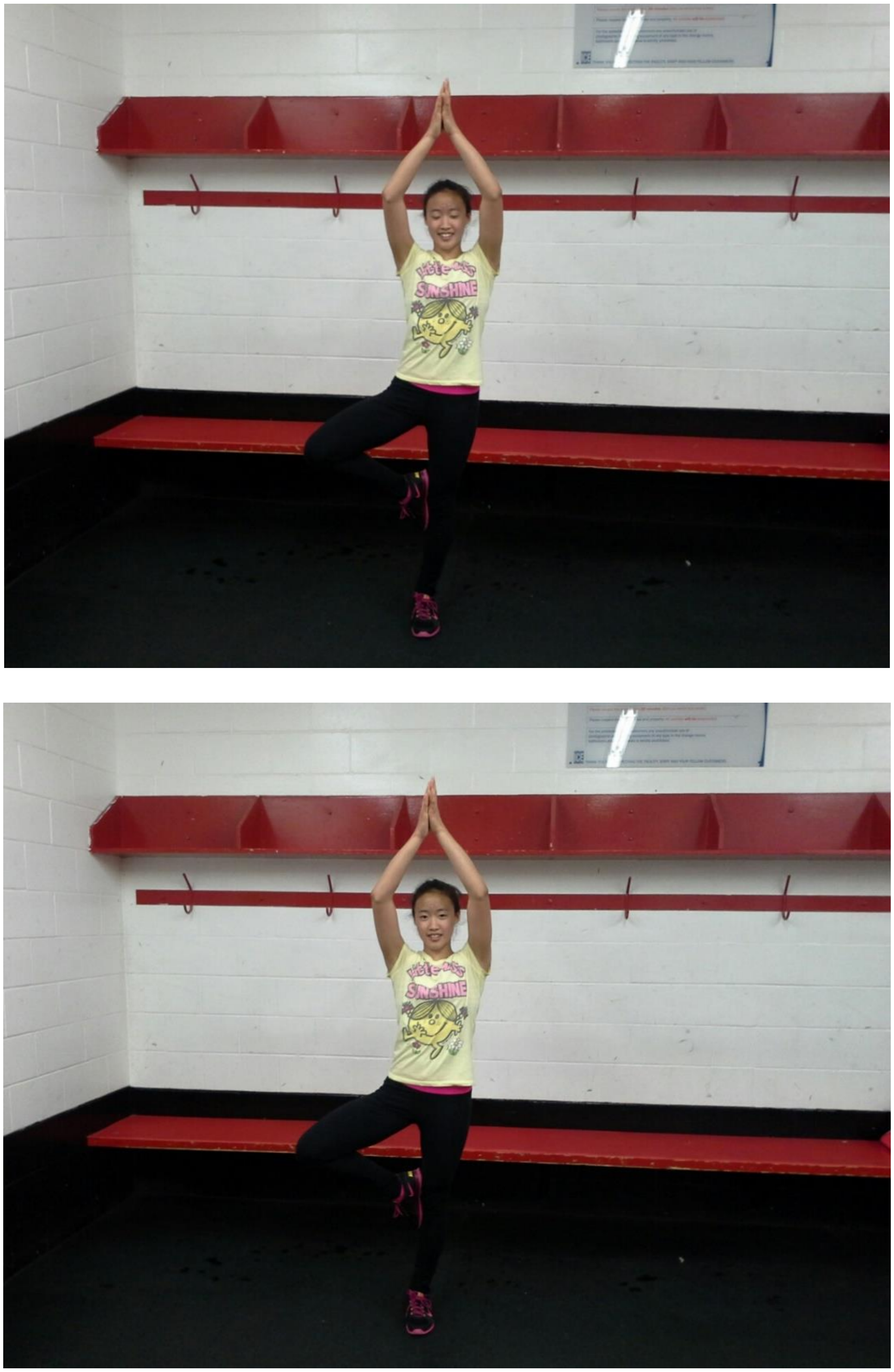


Figure 28: Skater performing Stork Stand Test for Balance

4.6 On-Ice Testing Measures

Five on-ice assessments were administered, including a test of speed, acceleration test, the axel jump, a sit spin, camel spin and the backspin. The axel (as a forward take-off jump) is selected because it is a required element in all single figure skating programs. The camel spin and sit spin were evaluated because they are required for any skater to achieve a basic combination spin (a requirement in all figure skating programs); while the backspin was assessed because it provides the basis for all jump rotations. A speed test was also be included to provide an indication of the basic skating capabilities of the skater. An acceleration test was also included at the request of Skate Canada.

4.6.1 Speed

A single lap speed test (Bower et al., 2010) was administered to assess skating speed and proficiency. To implement, an outline of the skating lap area was outlined with cones placed at the face off circles for ice hockey as well as the end zone hockey end. This test was modified for the investigation, wherein the skaters were provided approximately half of the ice surface to build up speed before the centre line (start of the test). This modification was implemented to cancel out the effects of acceleration. Skaters completed one lap of the course, and performance was determined as the time needed to cover the distance from center line to the crossing of the same center line. Three timers were used (two in the case of the Vancouver Island group) and the average of the times was used for analysis.

4.6.2 Acceleration

An on-ice acceleration test (Bower et al., 2010) was administered to assess skating acceleration. Skaters skated from blue line to blue line on a standardize hockey rink (15.24 m on North America rinks). Three timers were used (two for the Vancouver Island Group) and the average of the times were used for analysis.

4.6.3 Elements

Evaluations for the back spin, sit spin, and axel were determined by a consensus of three gold level judges (judges who have passed the Skate Canada criteria for judging up to gold levels tests in figure skating) according to the criteria set by the BC/YK Section STAR standards for categories. The elements will be assigned a value of Gold, Silver, Bronze or Merit as set out by the criteria. Performance of elements was also recorded by video tape for analysis purposes. Skaters were asked to perform the first element, until all skaters had performed the element. Then the next element was then assessed. Skaters were allowed to repeat the element if they did not feel it was consistent with their best performance, up to a maximum of three times. In the case of the Vancouver Island Group, only one judge assessed the skill along with a coach.

4.7 Statistical Analysis

Comuk and Erden (2012) ensued groups of 9 skaters and 11 skaters, based on division of skaters into groups by ability to execute a double axel versus those who could not, and were able to show statistical significance ($p \leq 0.05$). As this study included 28 skaters in total, nine skaters who could perform an axel versus 19 that could not, the study was able to reach statistical significance.

All statistical analyses were performed using IBM SPSS Statistics 22 software (UBC). Comparison of means was used to compare all the group physical fitness tests results of for those skaters who could successfully perform a single axel jump compared to those skaters who could not.

Regression analysis was used to examine possible correlations between the results of certain physical fitness tests to the performance of on ice skills such as the vertical jump to the performance of the axel.

4.8 Strengths Contribution of the Study

This study is the only one of its kind to investigate physical fitness of younger figure skaters filling a gap in the literature. It is also the first to link these abilities or constraints to the performance of skills on ice. It also the only study to measure agility in figure skaters. This study may provide information that can be used in coaches training manuals and may help clubs and coaches develop better training programs to help young figure skaters meet the demands of the sport and the skills involved.

4.9 Validity and Reliability

Validity is the degree to which a test measures what it meant to measure. As this study is focused on very young children, tests of maximum muscular strength that are acceptable for adults are not appropriate. Hand grip strength is an accepted test for upper body muscular strength in many fitness testing programs of children in schools but may not give a direct measure of the relative upper body strength for a skater needed to stop the rotation of the jump. In this respect, it may lack construct validity. Other tests included for upper body muscular strength such as the Plank and One-Minute Modified Push-Ups tests have more construct validity for figure skaters but are not as standardized and accepted as the Hand

Grip test. The tests for agility (T-test, and Hexagon Test) are accepted and recommended tests by the National Strength and Conditioning Associations' Essentials of Strength and Training and Conditioning, Second Edition. The Sit up test is a recommended test for muscular endurance and the One-Minute version is more acceptable for young children and is more reliable. The Seated Reach Test is also standardized test of flexibility from the National Strength and Conditioning Associations' Essentials of Strength and Training and Conditioning, Second Edition but is difficult to reproduce without equipment (the box) so the seated reach test was chosen based on its ability to be duplicated. However, this test does lack construct validity for other areas of flexibility such as flexibility in the lower legs. All other tests that have been included have been chosen to show a relationship between the physical fitness component being tested and the performance of skills in figure skating. The standing spiral and stork stand can be related to balance of the skater. The Seated Reach tests is related to the sit spin. Agility, timed tuck jumps, vertical jump as well as all tests of upper body and lower body strength and endurance is related to the on ice performance of the axel and the speed test. All tests have been chosen and performed by sport science specialists within the US Figure Skating Association or other standardized sport testing fields.

Reliability is the measure of the degree of consistency or repeatability of a test. To ensure reliability of all tests, skaters were allowed to perform many of the tests more than once so that their best performance was used for analysis. As the test subjects are young children, the likelihood of them making errors is very high so allowing for multiple attempts increased the reliability of the tests.

4.10 Ethical Considerations

Children are considered to be a vulnerable population; therefore all members of the physical fitness data collection team required a current criminal check. This is why only certified coaches were used for testing. All testers will possess appropriate training and qualifications, wherein all individuals were either be a certified figure skating coach or a qualified exercise professional. Assessments of on ice elements were performed by Gold Level judges as standardized by Skate Canada and the ISU.

Assent from the child, as well as informed consent from the parent was obtained prior to testing. All tests occurred in an open area in the venue, and a testers were never alone with a participant.

Once informed consent was obtained, skaters were assigned a coded number prior to data collection to ensure that their personal information was not identifiable. All data was recorded during testing on paper and then entered into an electronic file. Hard copies of all consent forms, data collection (testing forms), and questionnaires, have been stored in a locked filing cabinet in the Cognitive and Functional Learning Laboratory at the University of British Columbia, which is a secured by an alarm system. Electronic files are stored on password protected computer. At the conclusion of the research, all data is kept in the School of Health & Exercise Sciences Lab belonging to Phil Ainslie at the Faculty of Health and Social Development in the University of British Columbia Okanagan. This lab is only accessible by the main research team.

4.11 Knowledge Translation Plan

The results of this study will be presented to Skate Canada for their use in developing NCCP courses and training manuals for coaches of the Learn to Train Stage of development. The author will submit the findings for publication in a reputable journal. A Fact sheet will be created from the data regarding basic physical constraints and abilities observed as benchmarks for progress of developmental skaters Skate Canada has recognized the need for physical training to be included in developing a figure skater by incorporating a chapter on basic fitness information in their coaching manuals. The manuals gives information on what physical training is. The US Figure Skating Association has already developed a fitness testing system they call STARS (**S**tandardized **T**esting of **A**thleticism to **R**ecognize **S**katers). Over the past few years, they have been travelling to skating clubs to test skaters and have developed a database to give skaters information on where their fitness level lies within the skaters' age and category. As a coach, I would find it very useful to have a set of norms of physical fitness levels for developmental figure skaters as a tool for designing training programs appropriate for my skaters to balance the need for instructions on proper technique with creating and building the underlying physical foundations for the skills. As a parent, I would appreciate programs designed to maximize progress that is cost effective so that I am not pay expensive lesson time on technical skills for skaters who do not have the physical abilities to perform those skills.

CHAPTER FIVE RESULTS AND DISCUSSION

5.1 Introduction

This was the first study to investigate developmental figure skaters. The purpose of this study was to examine the relationship between physical fitness and skill related fitness compared to on ice performance of developmental figure skaters.

Twenty eight developmental female figure skaters between the ages of 6 and 14 who were currently competing in the STAR 2, STAR 3, STAR 4, or STAR 5 categories as outlined by the BC Section Competition criteria (part of the Learn To Train Stage of the Skate Canada Long Term Athlete Development Model) were tested over a one day period.

A total of ten off-ice physical assessments were administered, which included skill-related physical fitness tests of agility (T Test, Hexagon Test), and balance (Stork Stand); as well as health-related physical fitness tests: flexibility (Sit and Reach), muscular endurance (the One Minute Timed- Sit Ups, One Minute Modified Push-Ups, the Plank), muscular strength (Hand Grip), and power (the Timed Tuck Jumps and Vertical Jumps). On-ice assessments included a speed test and acceleration test to determine skating ability, as well as an assessment of four elements; the axel jump, the back spin, camel spin, and the sit spin.

Analysis of means of the two groups (skaters who could successfully perform an axel and those skaters who could not) were compared. Nine of the twenty eight skaters tested could perform the axel jump. Mean ages of the two groups are shown in Table 16. There was no statistical difference between the ages of the axel group compared to the non-axel group (*p=0.307*).

	NON AXEL GROUP (N=19)	STD DEV	AXEL GROUP (N=9)	STD DEV
AGE (YRS)	10.6	1.9	11.1	1.53
	p = 0.307			

Table 18: Mean Age of both Axel and Non-Axel group

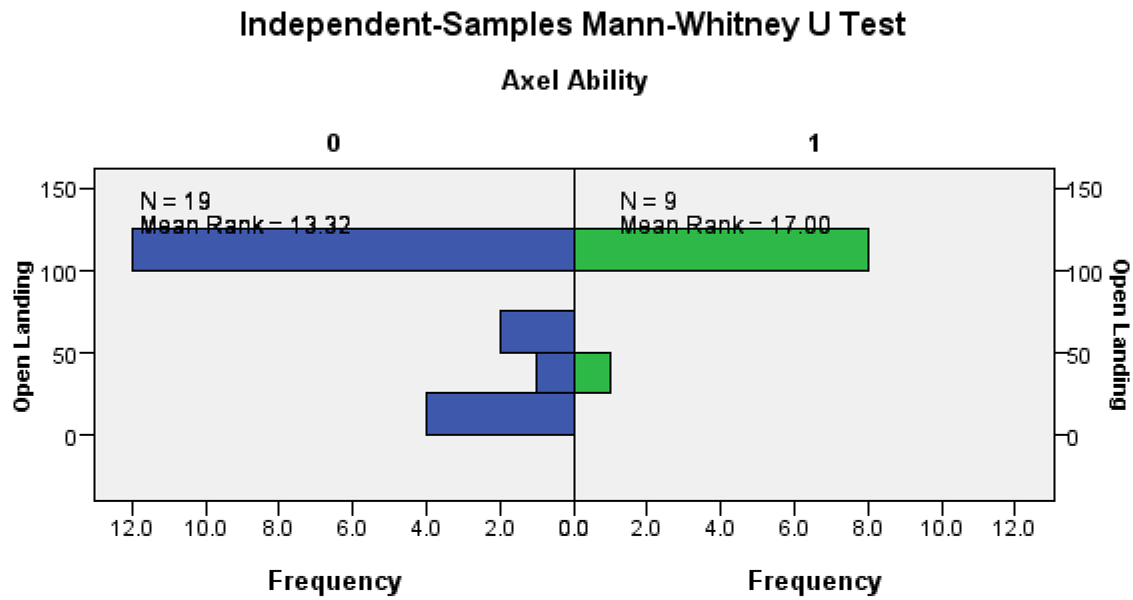
Based on test scores, mean results of physical tests for skaters who could successfully perform the single axel jump (n=9) were compared to the skaters who could not successfully perform the axel (n=19). There was no statistical significance for the vertical jump on both feet (with skates on as well as skates off), vertical jump on landing foot on the ice, balance with eyes open on the take-off foot, plank on the free-side, One-minute push-ups, grip strength with the right side, not either Hexagon agility test in either direction nor the T-test for agility. There was also no significant difference for the on-ice acceleration test. Significant differences at the $p<0.05$ level were found for vertical jump on the landing foot both on the ice with skates on, vertical jump on the take-off foot on the ice, 1-lap speed test, plank test on the skating side, and grip strength with the left hand. Significant differences at the $p<0.01$ level were found for all spins (Back spin, Sit spin, and Camel Spin), as well as vertical jump on the landing foot off the ice without skates on, balance with the eyes open on the on the landing foot, both balance tests of eyes closed on the landing foot and take-off foot, 30-sec timed-tuck jumps, seated reach, and One minute sit-ups.

Regression analysis comparing physical fitness to on ice performance showed significant correlations between the vertical jump and the 1-Lap Speed Test, the T-test for Agility and the 1-Lap Speed Test, and also the 30 second timed tuck jump and the on-ice acceleration test.

5.2 Physical Fitness and Performance Tests

Analysis of means of the two groups (skater who could successfully perform an axel those skaters who could not) were compared for physical fitness and on-ice performance tests. Mean scores and standard deviations for physical fitness tests are presented in Table 18. Initially, statistical T-tests were run on all physical fitness scores. The data did not pass Levene's test for normality with the exception of only the scores for balance with eyes open on the landing foot as shown in Figure 29 (Field, 2013). This is due to the fact that many skaters reached the maximum score for the balance test of being able to hold their balance for 120 seconds. All scores were then analyzed using non-parametric tests. Mann-Whitney U test scores were used to determine the significance of the difference between rankings of the axel group compared to the non-axel group having been ranked on the same variables (Vincent & Weir, 2012).   Mann-Whitney U-tests results are reported along with the corresponding z score (test statistic) and effect size(Field, 2013).

In addition to the above mentioned balance test having showed significance in both the T-test and non-parametric tests, both the seated reach test (*p=0.005, p=0.001*) and the 1 lap speed test of skating proficiency showed significance in both tests (*p=0.029, p=0.042*).



Total N	28
Mann-Whitney U	108.000
Wilcoxon W	153.000
Test Statistic	108.000
Standard Error	16.212
Standardized Test Statistic	1.388
Asymptotic Sig. (2-sided test)	.165
Exact Sig. (2-sided test)	.285

Figure 29: Model view of data scores for Balance Test on Landing foot with eyes open showing normality of data in comparison to non-parametric tests.

Physical Test	Mean (non Axel Group) n=19	Std Dev	Mean (Axel Group) n =9	Std Dev	P value – Mann-Whitney U test	Z score	Effect Size
Back Spin Revs	4.7	3.1	10.9	5.0	0.002**	3.0	0.57
Sit Spin Revs	2.5	2.5	6.8	3.2	0.002**	3.0	0.57
Camel Spin Revs	1.6	1.9	4.3	1.5	0.001**	3.3	0.62
Average Acceleration (sec)	4.1	0.3	3.8	0.2	0.078	-2.2	-0.42
Vertical Jump Off Ice Landing Foot (cm)	12.2	6.3	21.9	6.4	0.002**	2.9	0.55
Vertical Jump Off Ice Take Off Foot (cm)	11.7	6.9	16.4	4.4	0.019*	2.3	0.43
Vertical Jump OFF Ice Both (cm)	18.6	8.6	23.0	13.9	0.595	0.5	0.09
Vertical Jump On Ice Both (cm)	14.2	5.7	18.2	6.3	0.129	1.6	0.30
Vertical Jump On Ice Landing Foot (cm)	7.2	4.4	10.8	5.5	0.117	1.6	0.30
Vertical Jump On Ice Take Off Foot (cm)	6.1	4.2	11.2	6.3	0.033*	2.1	0.40
1 Lap Speed Test (sec)	20.7	2.7	19.0	0.8	0.042*	-2.0	-0.38
Balance Eyes Open Landing Foot (sec)	85.3	48.7	110.1	29.7	0.003**	1.4	0.26
Balance Eyes Open Take Off Foot (sec)	79.6	49.4	56.1	48.8	0.285	-1.2	-0.23
Balance Eyes Closed Landing Foot (sec)	13.7	26.2	87.0	47.4	0.000**	1.4	0.26

Physical Test	Mean (non Axel Group) n=19	Std Dev	Mean (Axel Group) n =9	Std Dev	P value – Mann-Whitney U test	Z score	Effect Size
Balance Eyes Closed Take Off Foot (sec)	15.7	26.1	35.1	28.4	0.003**	2.9	0.55
30 sec Timed Tuck Jumps (no.)	16.9	8.1	33.1	12.8	0.003**	2.9	0.55
Plank Free Side (sec)	49.3	20.0	63.3	24.3	0.142	1.5	0.28
Plank Skating Side (sec)	43.0	20.7	64.7	16.8	0.016*	2.4	0.45
One Minute Push-Ups (no.)	14.4	7.2	17.4	9.0	0.383	0.9	0.17
Grip Strength Right (kg)	16.2	3.5	20.7	6.5	0.085	1.7	0.32
Grip Strength Left (kg)	15.7	3.3	19.7	4.8	0.048*	2.0	0.38
Seated Reach (cm)	39.5	15.2	59.5	8.9	0.001**	3.2	0.60
One Minute Sit-Ups (no.)	24.2	6.6	32.1	6.0	0.004**	2.8	0.53
Hexagon Test – Non Rotational Direction (sec)	16.2	3.6	17.0	3.3	0.410	0.9	0.17
Hexagon Test – Rotational Direction (sec)	16.4	3.3	15.8	2.1	0.847	0.2	0.04
T-Test Agility (sec)	14.5	1.4	13.7	1.0	0.172	-1.4	-0.26
ᵡ *Statistical significance found using t-test. * Statistical significance set at p<0.05. ** Statistical significance set at p<0.01*							

Table 19: Physical Fitness scores of both Axel and Non-Axel group.

5.3 On-Ice Test Measures of Skating Ability

On ice test measures including assessments of speed and acceleration as well as an evaluation of skating skills including three spins and the axel jump.

5.3.1 Skating Ability by Spins

Non parametric test results show that the axel group were significantly better spinners on all three basic spins (back spin (*$p=0.002$*), sit spin(*$p=0.002$*), and camel spin (*$p=0.001$*)) as shown in Figures 30, 31 and 32.

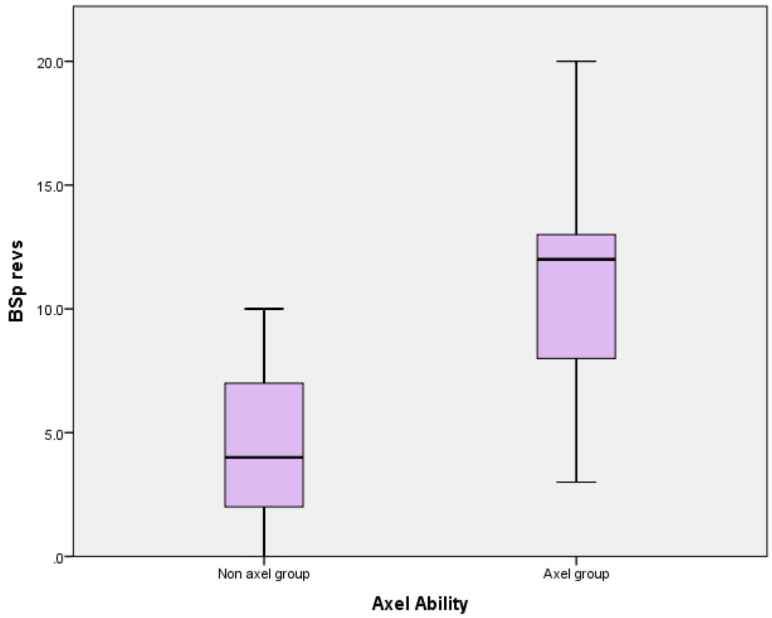


Figure 30: Number of Revolutions performed in Backspin by each group

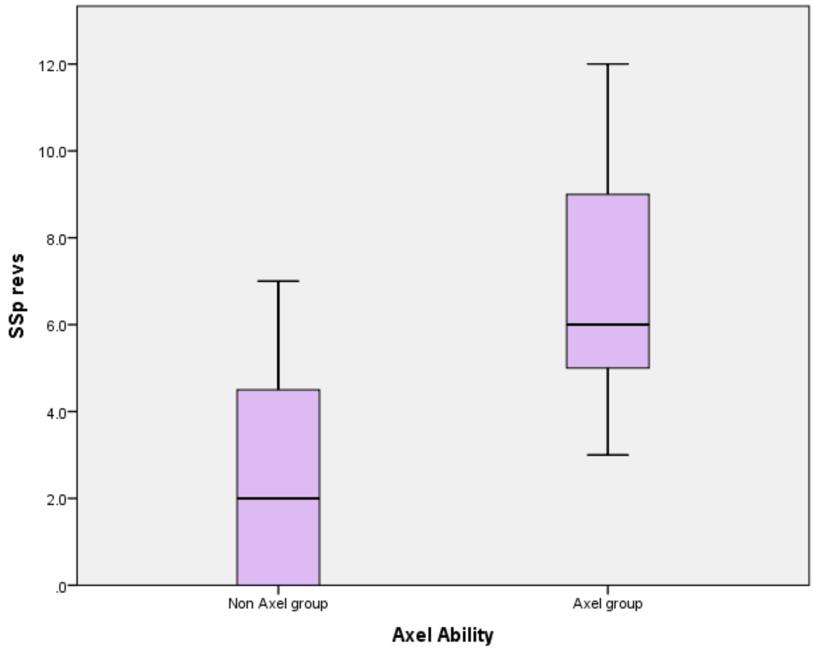


Figure 31: Number of Revolutions performed in Sit spin by each group

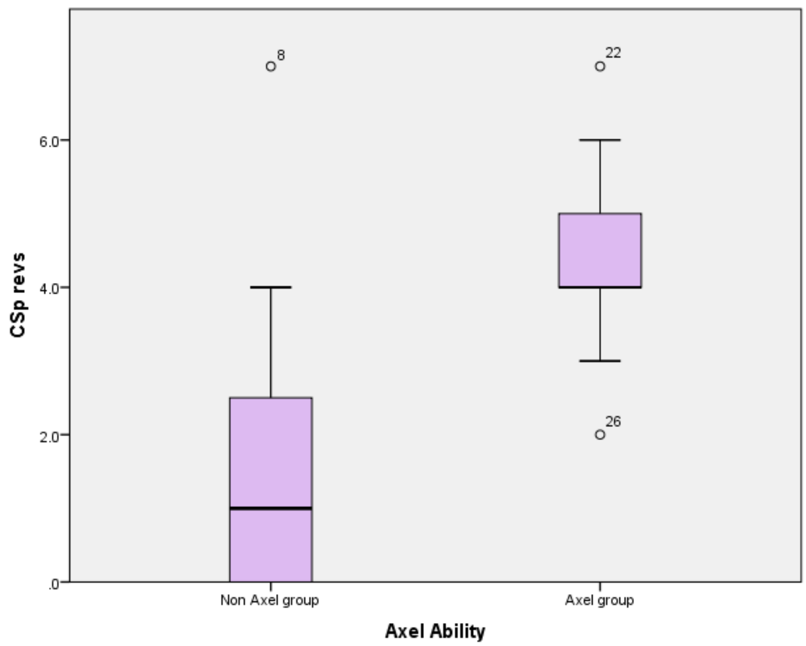


Figure 32: Boxplot of number of revolutions performed in Camel spin by group

Skaters in the axel group were also better spinners in terms of being able to hold their spins longer ($p=0.001$). Skaters in the axel group could complete an average of more than 4 revolutions in the proper position (mean = 4.3 ± 1.5revs) while the non-axel group could not quite complete the required 2 revolutions (mean =1.6 ± 1.9 revs). For sit spins, the axel group could complete an average of 6.8 ±3.2 revs and the non-axel group could only complete an average of 2.5 ± 2.5 revs ($p=0.002$). The back spin, which is the most important spin for developing rotational positions in the air (Mapelli et al., 2013) showed that the axel group could perform more than twice as many revolutions (mean axel group = 10.9 ± 5.0 revs compared to mean non-axel group 4.7 ± 3.1 revs, $p = 0.002$). This suggests and reinforces the importance of developing a strong rotational position in the back spin and that a strong backspin is fundamental in the success of an axel. As balance is also an important factor in spinning, this also suggest that balance plays a key role in the achievement of a single axel jump.

5.3.2 Skating Ability Speed and Acceleration

Skaters in the axel group completed the one lap speed test an average of 1.7 seconds faster (8.5%) than the non-axel group. Skaters in the axel group (19.0 ± 0.8s) were significantly more efficient skaters than the non-axel group (20.7 ± 2.7s, $p = 0.047$).

Results from the acceleration test did not show a significant difference in the two groups.

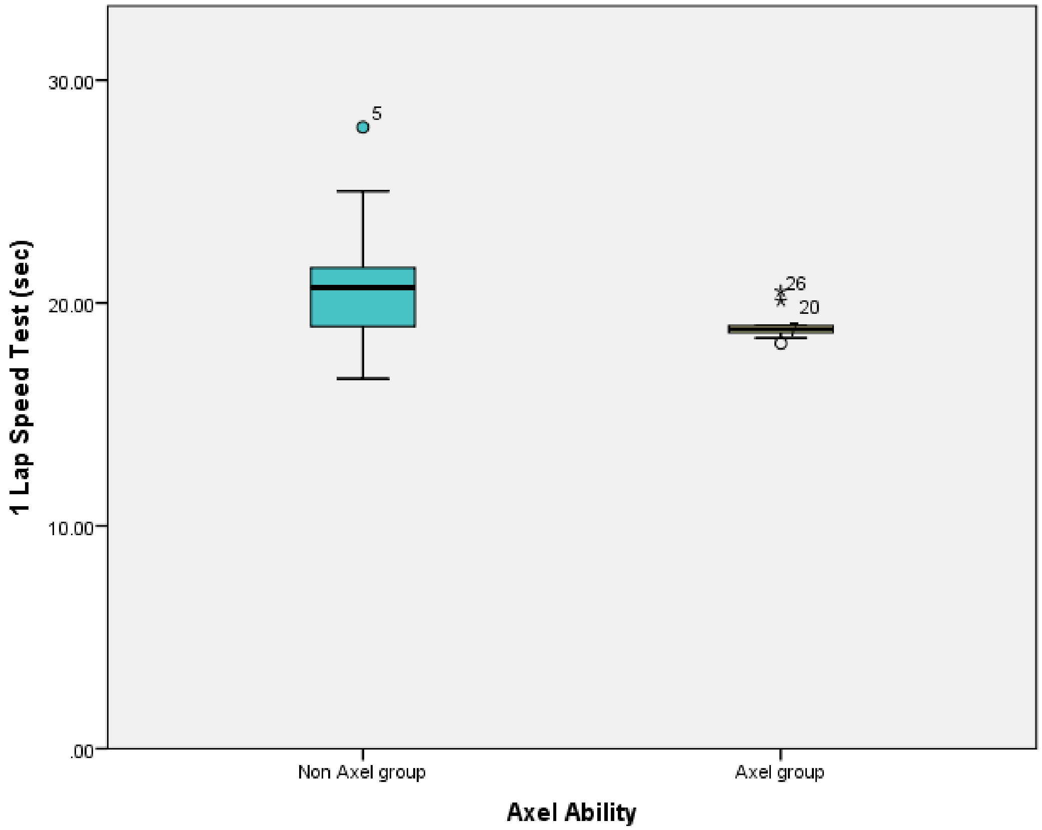


Figure 33: 1 Lap Speed Test results per group

5.4 Off-Ice Test Measures of Physical Fitness

Several components of skill-related and health-related fitness were assessed using standardized tests.

5.4.1 Balance

Balance is essential to the sport of figure skating for all disciplines because skaters have to be able to balance on their blades while turning, spinning, and gliding (US Figure Skating Association, 2013). This was the first study to investigate and assess balance in figure skaters without using advanced technology. The stork stand was implemented to assess an athlete's capability to balance on one foot and because it can be duplicated by coaches and personal trainers.

Balance scores of the two groups showed that axel group had better balance with their eyes open while on the landing foot using the T-test (p=0.003). Non parametric analysis showed better balance in the axel group for the take-off foot with eyes closed (p=0.003), while both tests showed that the axel group had better balance with the eyes closed on the landing foot as shown in Figure 34.

Three of the four balance assessments showed that skaters who could land their axel had significantly more balance on their landing foot (p = 0.000) with their eyes closed. Skaters who could not perform an axel could only hold this position an average of 13.7 ± 26.1s compared to the axel group who scored almost six times greater, holding an average of 87.0 ± 47.4 s with many of them reaching the maximum score for this test of 120s. This may also suggest that these skaters lack the same anxiety to land on one foot than the skaters who could not perform an axel. When performing the test with eyes open both groups were able to hold their balance longer but the axel group (85.3 ± 48.7s) still out achieved the non-axel group (110.1 ± 29.7s), ($p<0.003$). The axel group also achieved higher scores on the balance test on their take-off foot with their eyes closed (axel group = 35.1± 28.4s compared to non-axel group = 15.7 ± 26.1s, $p<0.003$). These results suggest that balance is a key factor in the ability to successfully land an axel jump. Table 19 shows testing norms for the Stork Stand (Eyes Open) for ages 16-19 yrs. The researcher could not find normative data for children matching the ages involved in this study. However, these testing norms show that skaters need to have excellent balance compared to average people. Even the non-axel group scored in the excellent range.

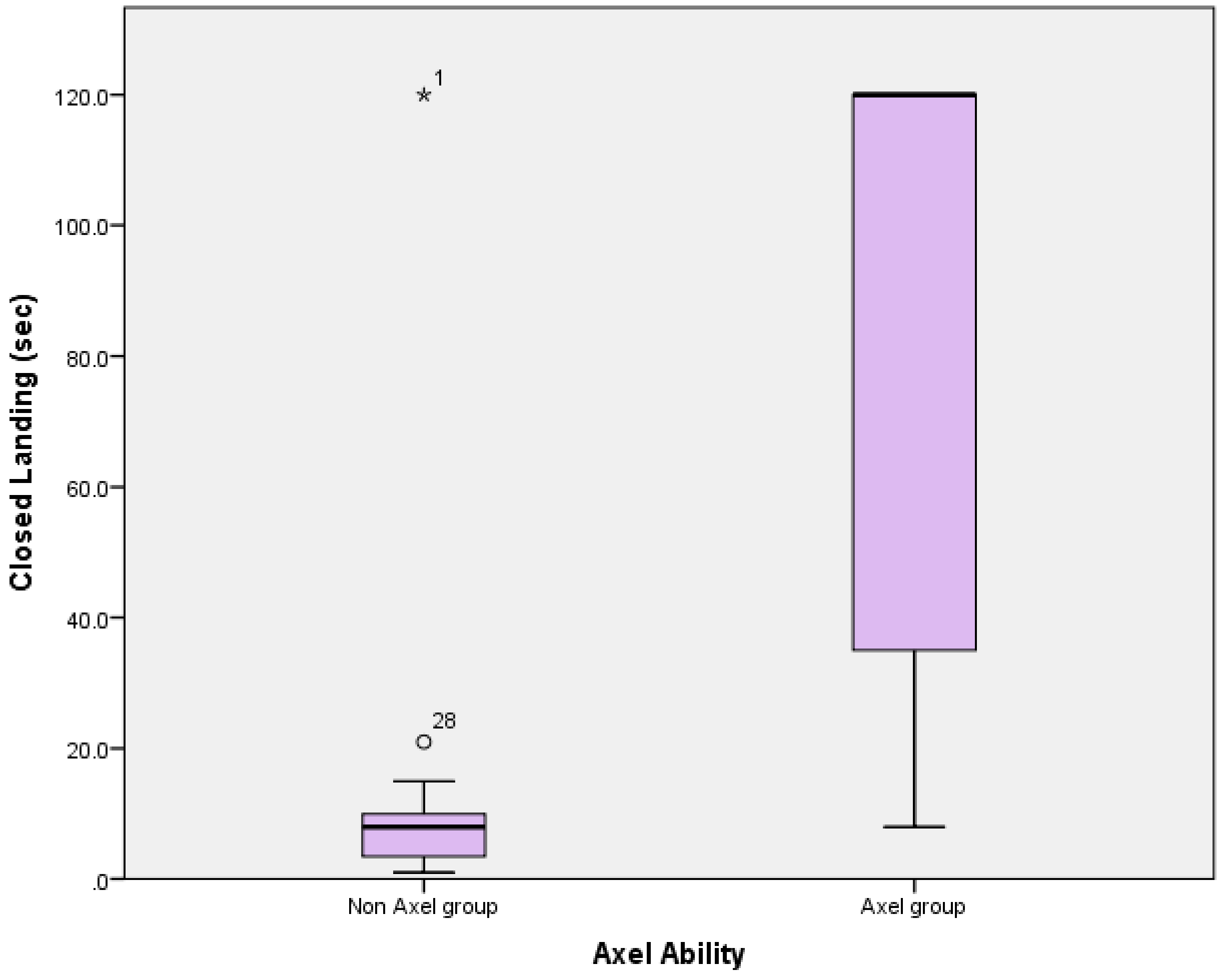


Figure 34: Balance scores of number of seconds until losing balance on the skater's landing foot with their eyes closed.

Rating	Males	Females
Excellent	>50	>30
Above Average	41-50	23-30
Average	31-40	16-22
Below Average	20-30	10-15
Poor	<20	<10

Table 20: Normative Data for 16-19 year olds

Balance has been researched in figure skaters in several studies (Alpini et al., 2008; Kovacs et al., 2004; Saunders et al., 2013). These investigations used technology such as force plates in lab settings for assessing the balance or postural control of the skaters. None of the previous studies were able to relate balance to performance other than Saunders et al (2013) who showed that higher level skaters were able to increase their balance during a 6 week neuromuscular training program 25% more than the less skilled skaters.

However, all of these studies concluded that off -ice conditioning programs emphasizing balance and ankle stability should be incorporated into the normal training programs of skaters (Saunders et al., 2013). It is highly recommended that off-ice training programs for developmental figure skaters incorporate balance training into their programs.

5.4.2 Flexibility

Flexibility was measured using the Seated Reach Test which is different from the standard sit and reach test. Skaters in the non-axel group measured a reach of average of 39.5cm ±15.2cm while the axel group showed significantly more flexibility by reaching an average of 59.5cm ± 8.9cm. The axel group was far more flexible around their core ($p=0.001$).

Figures 34 shows the mean scores of both groups on the Seated Reach test. There is no normative data for the Seated Reach Test though it is a much easier test to administer as it does not require the use of the Sit and Reach box and this Seated Reach Test can be duplicated by anyone. This is why it is used as the standard test in the USFSA STARS testing program. Flexibility is known to be a very important physical necessity in figure skating yet it has not been widely researched as a constraint. Two studies (Kujala, 1997; Smith et al., 1991) related lack flexibility to pain in the lower back (Kujala 1997) and knee pain (Smith et al.,1991). Leone et al., (2002) was the only study to perform a basic flexibility test of figure skaters using the Sit and Reach Test but those results were only compared to age matched athletes of other sports.

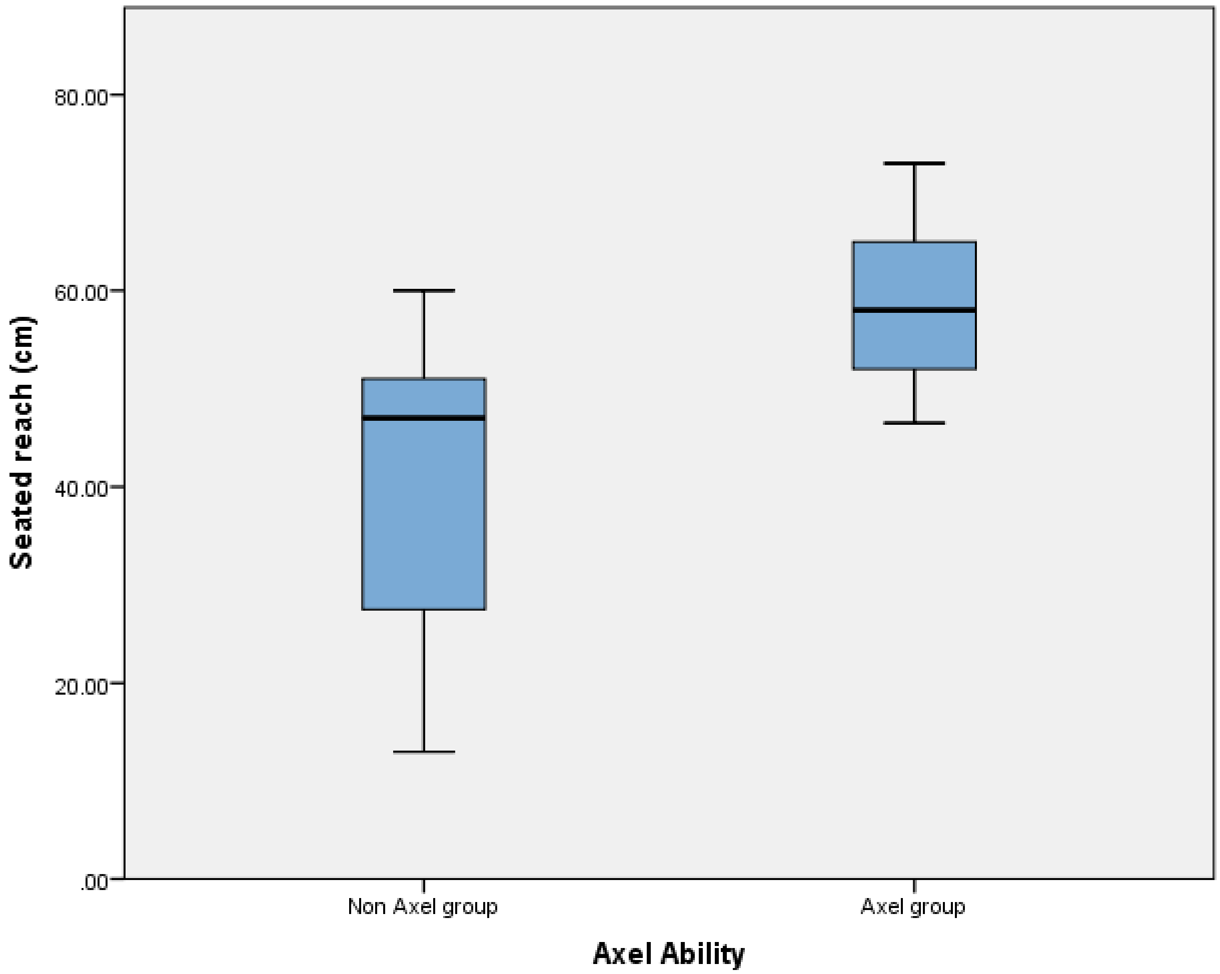


Figure 35: Results of Seated Reach test by group

5.4.3 Muscular Endurance

Muscular endurance in figure skaters is required at the elite levels to complete triple jumps near the end of a 4 minute program as well as combination jumps and complicated spin positions. The axel group performed significantly better than the non-axel group at the $p<0.01$ level in both the one-minute sit-ups ($p=0.004$) and the 30 second timed-tuck jumps ($p=0.003$).

5.4.3.1 Sit-Ups

Skaters in the axel group scored 25% better by completing and average of 32.1 ± 6.0 sit-ups in the one minute while the non-axel group could only complete and average of 24.1 ± 6.6 sit-ups in the one minute. Comuk & Erden (2012) was the only other study to use the one-minute sit-ups test and they found that their double axel group scored higher than their no double axel group though it did not reach statistical significance. However, it is interesting to note that their double axel group scored similar to our axel group in this study while their no double axel group scored similar to our non-axel group even though the skaters were much older as shown in Table 20.

The axel group scored in the 50th percentile range for number of sit-ups performed in one minute for their peers while the non- axel group scored around the 25th percentile group ("No ExRx.net Exercise Prescription," 1999).

	COMUK & ERDEN (2012)		PRESENT STUDY	
	Double Axel (n=9) Mean and SD	No Double Axel (n=11) Mean and SD	Axel (n=9) Mean and SD	No Axel (n=28) Mean and SD
AGE (YEARS)	18.55 ±2.92	19.09 ±2.62	10.6 ± 1.9	11.1 ± 1.53
SIT-UPS (# PER MINUTE)	33.44 ± 6.34	26.27 ±10.03	32.1 ± 6.0	24.1 ± 6.6

Table 21: Comparison of Comuk & Erden (2012) One Minute Sit-Ups to Present Study

5.4.3.2 Timed Tuck Jumps

Timed tuck jumps were tested because the movement is similar to the requirements of combination jumps which is a required element in all figure skating programs. The axel group were able to complete almost double the amount of tuck jumps (33.1 ± 12.8) compared to the non-axel group (16.9 ± 8.1). The only other study to utilize a repeated jump test was Sands et al., (2012) who found that they could predict approximately 50% of the competitive rankings of elite pair teams based on the power index generated from their test scores of off-ice repeated jumps. There are no standardized timed tuck jump norms for children to date.

Scores for skaters in the timed tuck jumps did show a correlation to their time in the acceleration tests as shown in Figure 40 and Table 24. This is similar to the findings of Bower et al., (2010) who did not use a timed tuck test but found that the on-ice acceleration scores could be predicted by the vertical jump scores or slide board count test scores.

5.4.3.3 Plank

Of the two plank tests, only the scores for plank tests on the skating side showed statistical significance (p=0.016). Skaters in the axel group could hold their plank position almost 20 seconds longer (63.3 ± 24.3s) then the non-axel skaters (43.0 ± 20.7s). Results from the free side plank test yielded similar results (axel group = 63.3 ± 24.3s, non-axel group = 49.3 ± 20.0s) but did not reach statistical significance (p=0.142). There is no standardized normative data for plank tests in children of this age for comparison.

5.4.3.4 Push-Ups

The only other muscular endurance test used was the one-minute push-up test which showed that the axel group could perform and average of 3 more push-ups (17.4 ± 9.0) than the non-axel group (14.4 ± 7.2) but did not reach statistical significance (p=0.383). However, Comuk & Erden (2012) showed that their double axel group was much stronger in the one-minute push-up test (36.22 ± 10.28) compared to the no double axel group (25.00 ±7.34), (p=0.011). Leone (2002) tested figure skaters using the push-up to exhaustion method on female skaters who were much older than the ones in our study aged (14.3 ± 1.3 years) and those skaters performed an average of 36.7 ± 13.5 push-ups.

Both groups in our study scored in the average range for their ages for number of push-ups performed in one-minute ("No ExRx.net Exercise Prescription," 1999). Results show that core abdominal strength is a key factor in landing a successful jump while upper body strength may not play a role until skaters are attempting to master jumps with two rotations or more.

5.4.4 Agility

Prior to this study there was no investigation into the agility ability of figure skaters. Skaters in this study did not show a significant difference in agility abilities for the skaters who could land their axel jumps compared to those who could not in all three agility tests. However, there was a correlation between the T-test scores for agility and the skater's time in the one lap speed tests as shown in Figure 41 and Table 25.

5.4.5 Muscular Strength and Power

Muscular strength is a health-related component of physical fitness that relates to the amount of external force that a muscle can exert (Caspersen et al., 1985) . Muscular strength is required most importantly for jumps and skating power and speed (Aleshinsky et al., 1994; Bower et al., 2010; King et al., 2004; Podolsky et al., 1990). Muscular strength was assessed using the hand grip strength for upper body strength and the vertical jump test for lower body strength and explosive power. Vertical jump power was a significant factor in three out of the six vertical jump tests.

5.4.5.1 Vertical Jump

The axel group showed more strength in terms of one foot vertical jumps regarding their landing foot (p=0.002), and take-off foot (p=0.019) as well as the take-off foot with the skates on (p=0.033). Results of the vertical jumps tests are summarized in Table 21.

	Mean (non Axel Group) n=19	Std Dev	Mean (Axel Group) n =9	Std Dev	P value
Vertical Jump Off Ice Landing Foot (cm)	12.2	6.3	21.9	6.4	0.002**
Vertical Jump Off Ice Take Off Foot (cm)	11.7	6.9	16.4	4.4	0.019*
Vertical Jump OFF Ice Both (cm)	*18.6*	*8.6*	*23.0*	*13.9*	*0.595*
Vertical Jump On Ice Both (cm)	14.2	5.7	18.2	6.3	0.129
Vertical Jump On Ice Landing Foot (cm)	7.2	4.4	10.8	5.5	0.117
Vertical Jump On Ice Take Off Foot (cm)	6.1	4.2	11.2	6.3	0.033*
***Significance at the p<0.05 level. ** Significance at the p<0.001 level.**					

Table 22: Vertical Jump Test Scores

Normative data for vertical jump scores in children are limited. A study by Taylor et al (2010) created normative data for vertical jumps scores for girls (one performed on both feet). According to this study, our non- axel group (vertical jump -both feet off the ice/no skates) scored 18.6 ± 8.6cm is just under the 25th percentile for vertical jump scores of girls aged 11 years (Taylor et al., 2010). While the axel group (23.0 ± 13.9cm) was just above the 25th percentile. Test results for skaters in this study were entered into the Exercise Prescription website vertical jump performance calculator. The non-axel group had poor vertical jump scores compared to the axel group who scored fair ("No ExRx.net Exercise Prescription," 1999). As this is the first study to test the vertical jump scores of skaters who are only working on single jumps and are not regularly training double jumps, the scores indicate that there is not a significant amount of strength required to perform single jumps compared to non-athletes. While the axel group skaters showed a significant increase in strength compared to the non-axel group, the scores were still not significantly high compared to non-athletes. This may indicate that strength begins to become a constraint when skaters begin training multi-revolution jumps.

Scores for skaters in the vertical jump test (no skates/off ice/both feet) showed a correlation with skater's time in the one lap speed tests as shown in Figure 42 and Table 25. These findings are similar to those of Bower et al., (2010) in which they reported that vertical jump height significantly correlated with on- ice single lap test ($r = 0.692$; $p = 0.001$).

Delistraty et al., (1992) created an physiological profile of skaters from club where the skaters ranged in age from 9-17 years and in skating level (Preliminary to Junior) and showed an average vertical jump score of 37.1 ± 8.4cm which is not useful for comparison because of differences in age and level as many skaters were older and many could have been training double or triple jumps.

Only three studies have measured the jump height of skaters' off-ice while several kinematic studies measured jump height on the ice. Podolsky et al., (1990) measured on ice jump height correlated to strength, but not off-ice measures of vertical jump height. Haguenauer et al., (2006) showed that wearing skates does alter the biomechanics of off-ice vertical jump performance in measures of squat jumps. The researchers did not collect any information on height obtained in the air. To the authors' knowledge, there have been no studies that directly relate off-ice vertical jump performance to on-ice jump height or performance. Delistraty et al., (1992) reported a mean vertical jump height of 37.1 (8.4) cm for skaters of different proficiency levels. Bower et al (2010) reported a mean vertical jump height of 45.16 (5.79) cm for elite synchronized skaters who do perform any jumps in their routines. No studies have reported vertical jump parameters related to skaters level or age. Delistraty et al., (1992) was the only study to measure vertical jump power, anaerobic capacity or anaerobic power in figure skaters though the means are averages of skaters of different levels, ages and proficiencies.

		Off-Ice (no skates)			**On-Ice (with Skates**		
		Take Off Foot	Landing Foot	Both	Take Off Foot	Landing Foot	Both
Off-Ice (no skates)	Take Off Foot		0.624**	0.596**	0.530**	0.474*	0.341
	Landing Foot	0.624**		0.382*	0.576**	0.589**	0.366
	Both	0.596**	0.382*		0.203	0.281	0.213
On-Ice (with Skates	Take Off Foot	0.530**	0.576**	0.203		0.731**	0.557**
	Landing Foot	0.474*	0.589**	0.281	0.731**		0.618**
	Both	0.341	0.366	0.213	0.557**	0.618**	
	*** Correlation is significant at 0.01 level, * Correlation is significant at the 0.05 level.*						

Table 23: Regressional Analysis Co-efficients for Vertical Jump Scores

Results from regression analysis (Table 22) comparing the vertical jumps of skaters with their skates on compared to when they had their skates off as in normal vertical jump testing procedure showed that the skates drastically reduce the vertical jump by approximately 50%. As well, the vertical jumps of the one foot tests were between 30-50% less compared to two feet. This findings coincide with Haguenauer et al., (2006) who concluded that a skaters' skates decreased the performance of jumping because of the mass as well as the limited plantar flexion (Haguenauer et al., 2006).

Results from other studies (Bower et al., 2010; Comuk & Erden, 2012; Delistraty et al., 1992; Podolsky et al., 1990) showed that strength is an important factor in performance of higher level figure skaters though none of their testing methods were duplicated in this study as they used technology and lab like settings. Comuk & Erden (2012) reported that the increased strength was necessary for double axel performance. They reported significant differences in strength in the right knee extension, and both left and right plantar ankle flexion for skaters who could perform double axels compared to skaters who could not. Podolsky et al., (1990) related jump strength measures to biomechanical performance. Those researchers also compared strength measurements to jump height of both single and double axels and found that highest correlations for jump height of an axel were obtained with the knee extension (240°/sec), hip extension (240°/sec), should adduction (300°/sec) and shoulder abduction (300°/sec). Both the single and double axel showed knee extension as the primary strength parameter but that in the double axel, shoulder abduction was an important secondary strength parameter. Bower et al., (2010), included only synchronized skaters and showed a moderate but significant correlation of right hip abductors to on ice acceleration. All studies included skaters at an elite level of their disciplines and are not directly comparable to results from this study.

5.4.5.2 Grip strength

Grip strength was determined based on left and right hand strength and not dominant hand versus non dominant hand as the dominance of hand does not necessarily coincide with the preference for rotational directions in figure skaters. The axel group (19.7 ± 4.8 kg) showed a significant difference (p=0.048) in the grip strength measures compared to the non-axel group (15.7 ± 3.3 kg) in the left hand only. However, there was no significant difference in grip strength in the right hand (axel group 20.7 ± 6.5kg compared to non-axel group 16.2 ± 3.5 kg) even though the axel group scored higher, it did not reach statistical significance (p=0.085). This suggests that there is an upper body strength requirement for performing the axel jump. This is likely due the amount of strength required to stop the rotation and maintain core strength and balance throughout the jump. Compared to children of the same age, both groups scored normal for their age ranges for strength in both hands (Wood, 2001).

5.5 Regression Analysis of On-Ice Performance using Physical Fitness Test Results

Regression analysis was done using Spearman's Rho coefficient analysis as the data collected was already proven to be non-parametric. Vertical Jump results for skaters with their skates on were compared to their own vertical jump without their skates on. Examination of correlations between vertical jump tests are shown in Table 23.

		OFF-ICE (NO SKATES)			ON-ICE (WITH SKATES		
		Take Off Foot	Landing Foot	Both	Take Off Foot	Landing Foot	Both
OFF-ICE (NO SKATES)	Take Off Foot		0.624**	0.596**	0.530**	0.474*	0.341
	Landing Foot	0.624**		0.382*	0.576**	0.589**	0.366
	Both	0.596**	0.382*		0.203	0.281	0.213
ON-ICE (WITH SKATES	Take Off Foot	0.530**	0.576**	0.203		0.731**	0.557**
	Landing Foot	0.474*	0.589**	0.281	0.731**		0.618**
	Both	0.341	0.366	0.213	0.557**	0.618**	
	*** Correlation is significant at 0.01 level, * Correlation is significant at the 0.05 level.*						

Table 24: Correlation coefficients of Vertical Jump Tests

Comparisons of vertical jumps of skaters (n=28) without their skates on compared to having their skates on during the on-ice tests are shown in Figures 36 (Both Feet), 37 (Landing Foot) and 38 (Take-off Foot).

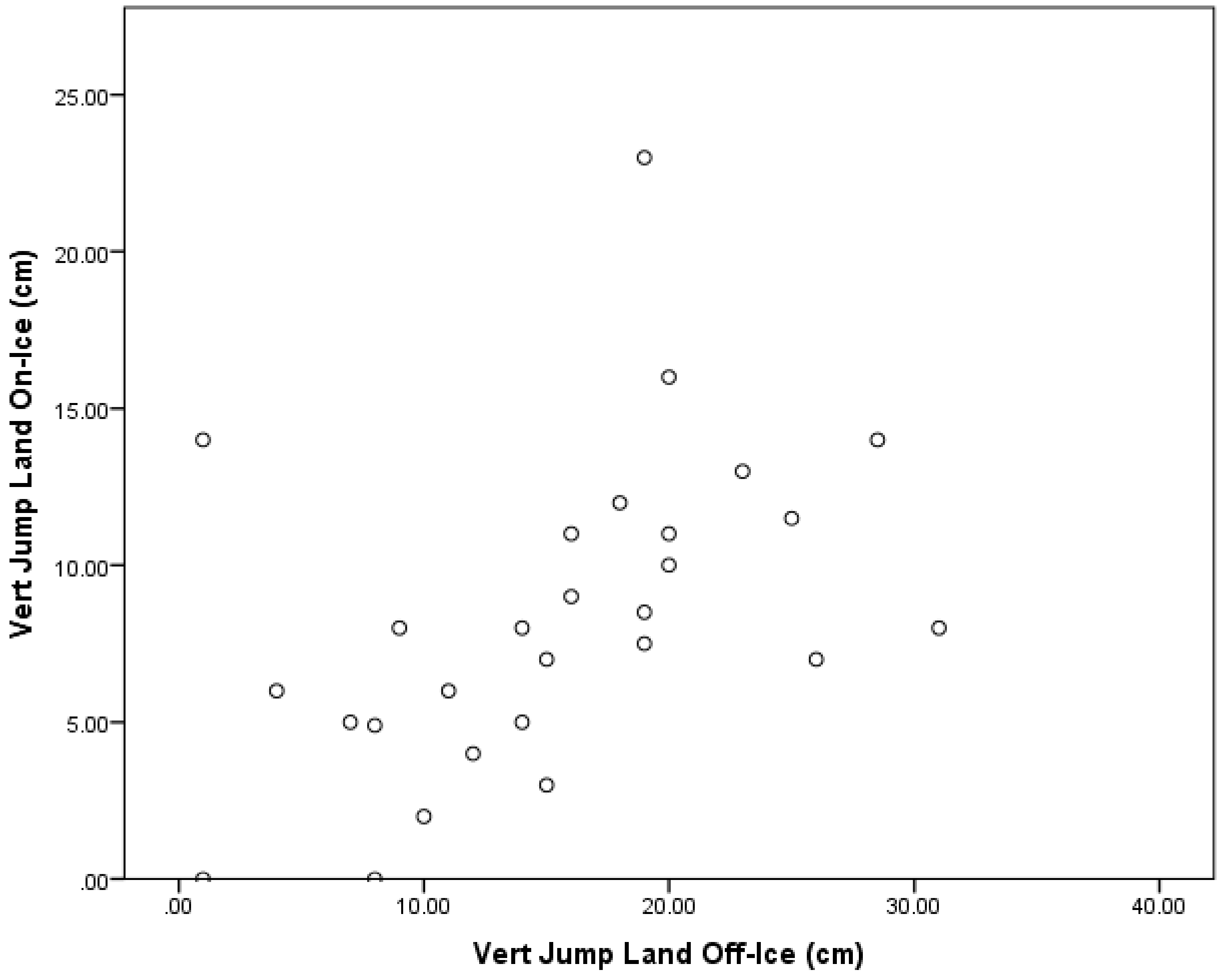


Figure 36: Comparison of Vertical Jumps of Landing Foot With Skates on and Off

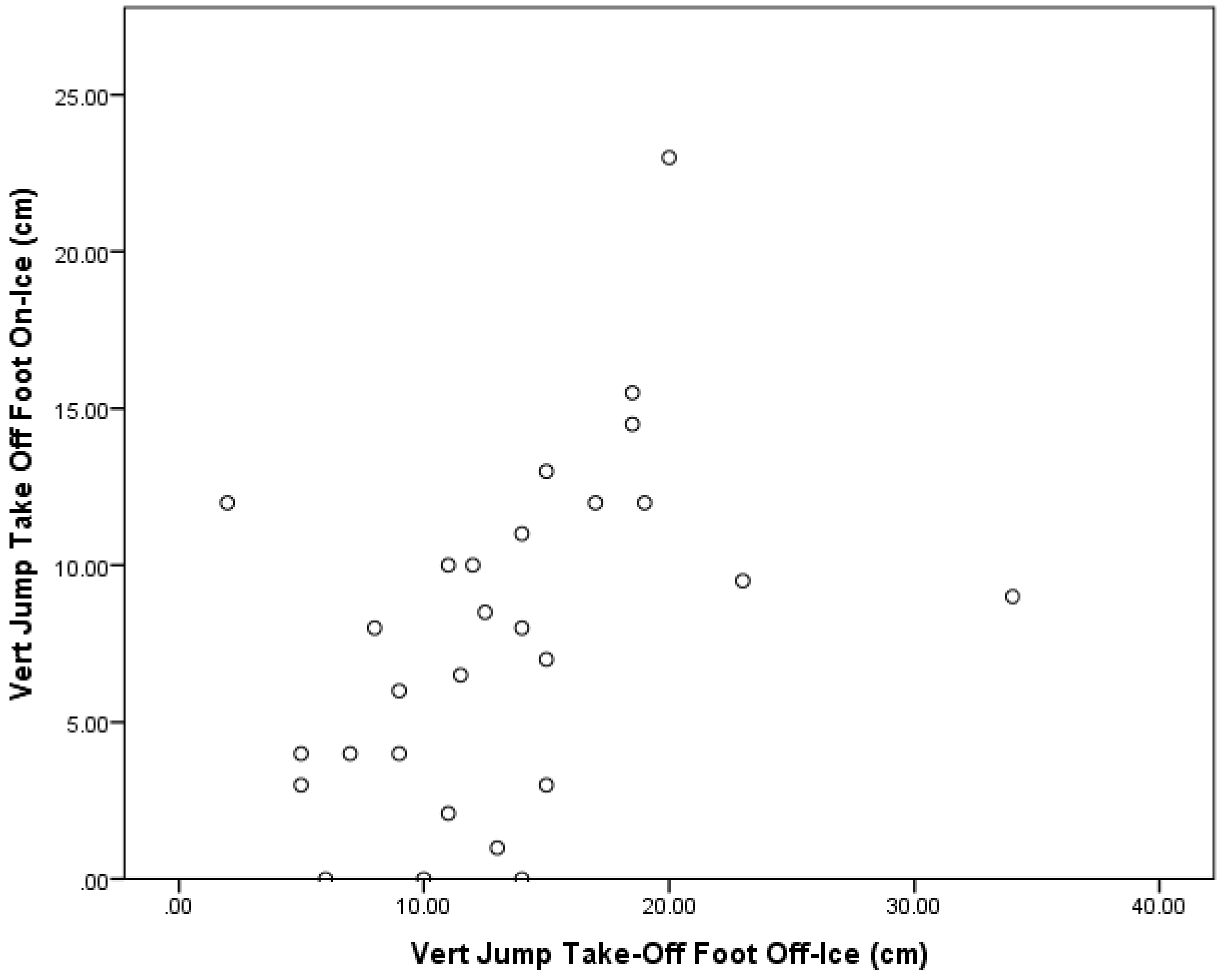


Figure 37: Comparison of vertical jump on Take-Off foot with and without skates on

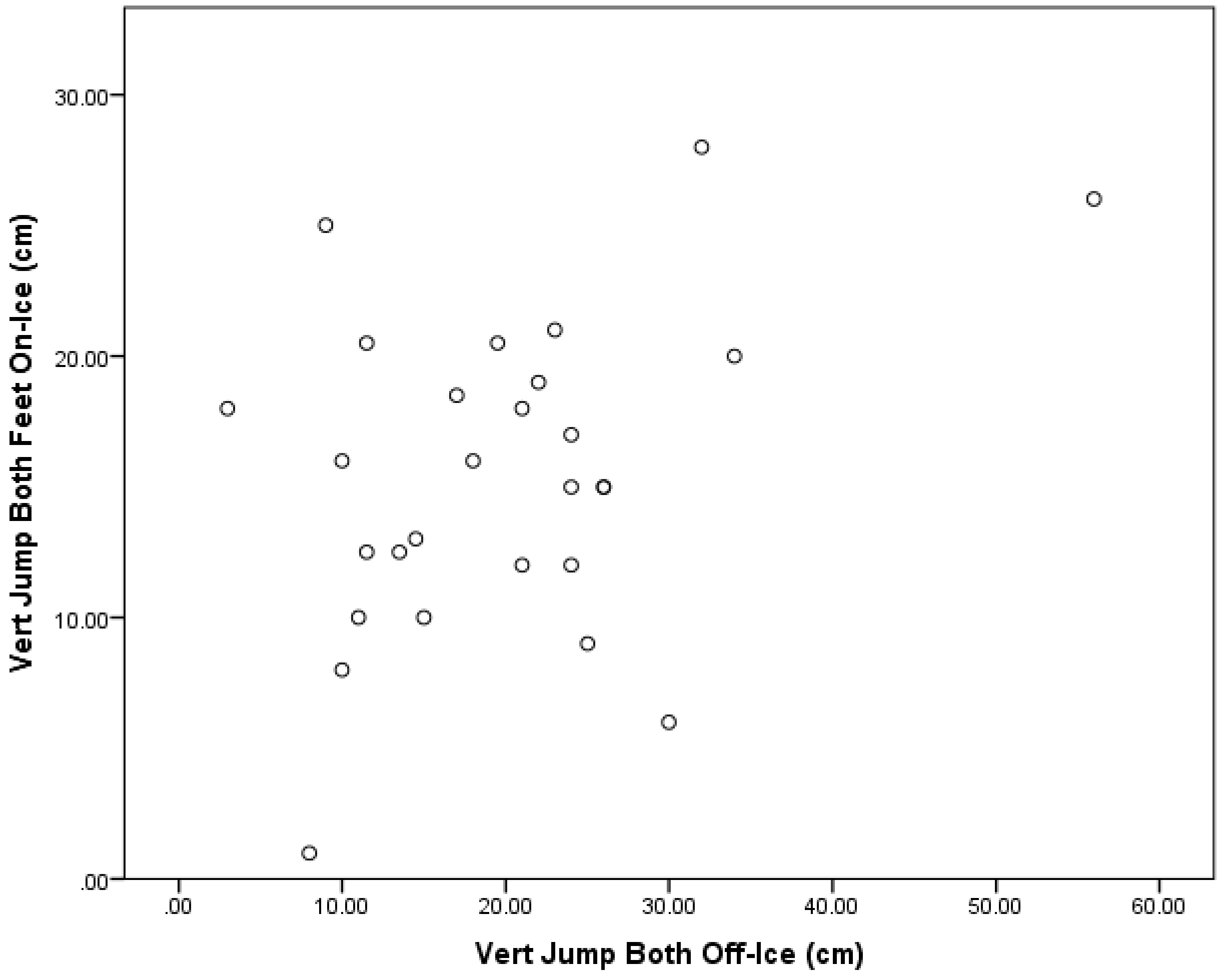


Figure 38: Comparison of vertical jump using both feet with and without skates on. (Correlation was not significant)

Physical fitness scores of lower body power (T-test, 30-second timed tuck jumps, and vertical jump) were then compared to the on-ice performance scores of speed (1 Lap Speed Test) and Acceleration. Correlations between off-ice physical tests compared to on ice performance tests using speed and power are shown in Table 25. Graphs of significant correlations for 30 second timed tuck jumps and the acceleration test are shown in Figure 39. Graph of correlations for the 1 Lap Speed Test are shown in Figures 40 (T-test of agility) and 41 (Vertical Jump).

	MEAN	STANDARD DEVIATION
AVERAGE ACCELERATION (SEC)	4.00	0.06
1 LAP SPEED TEST (SEC)	20.13	0.44
30 SEC TIMED –TUCK JUMPS (NO.)	22.1	2.3
T-TEST AGILITY (SEC)	14.3	0.3
VERTICAL JUMP (CM)	20.0	2.0

Table 25: Means and standard deviations for both on-ice and off-ice physical performance tests

		ON – ICE PERFORMANCE TESTS	
PHYSICAL FITNESS TESTS		**Acceleration (sec)**	**1-Lap Speed Test (sec)**
	30 second timed-tuck jumps (No.)	-0.447*	0.033
	Agility T-Test (sec)	0.259	0.446*
	Off-Ice Vertical Jump (cm)	0.079	-0.412*
	*Correlation significant at the 0.05 level.		

Table 26: Correlations of Off-Ice Physical Performance Tests and On Ice Performance tests.

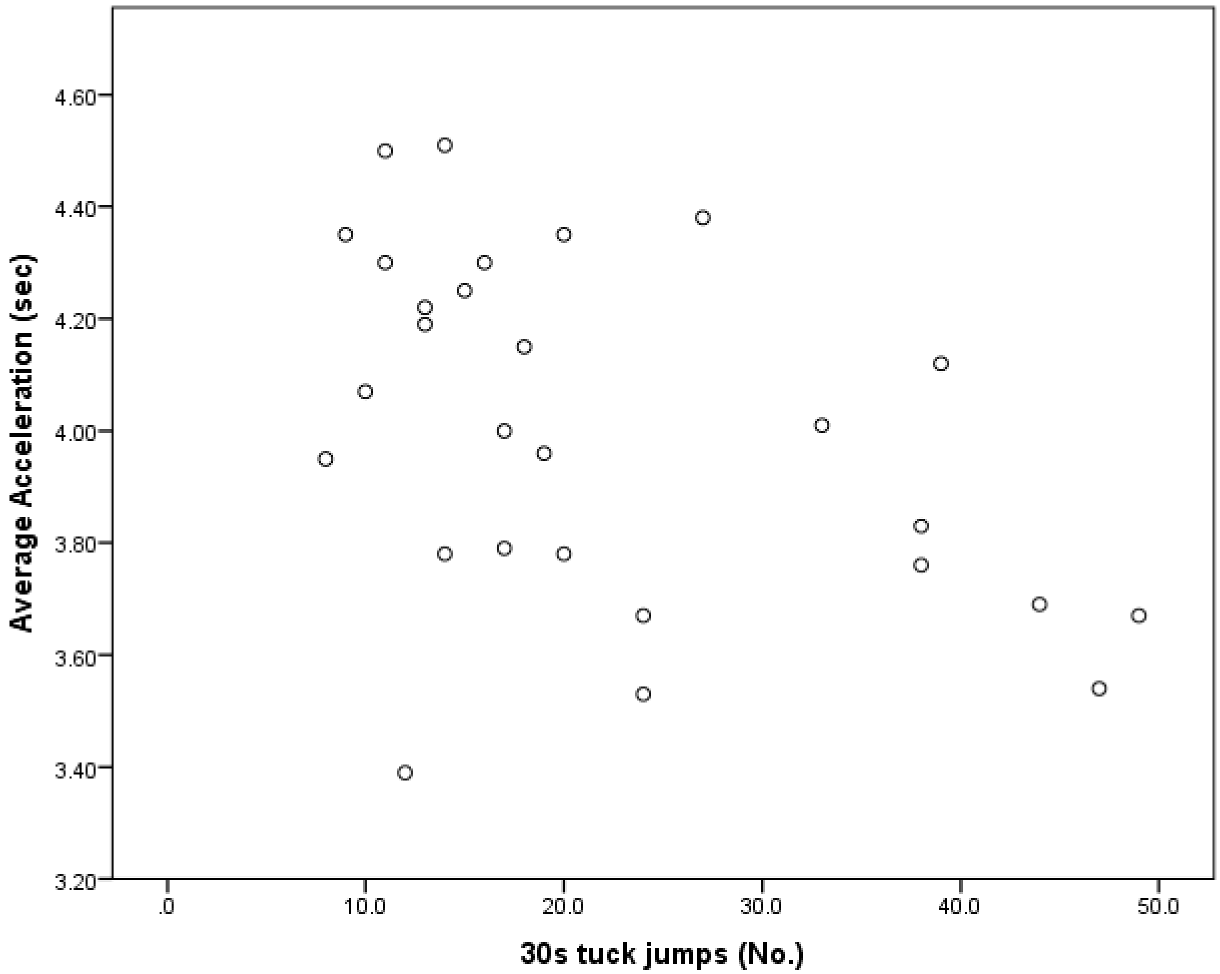


Figure 39: On-Ice Acceleration and 30-second timed tuck jumps

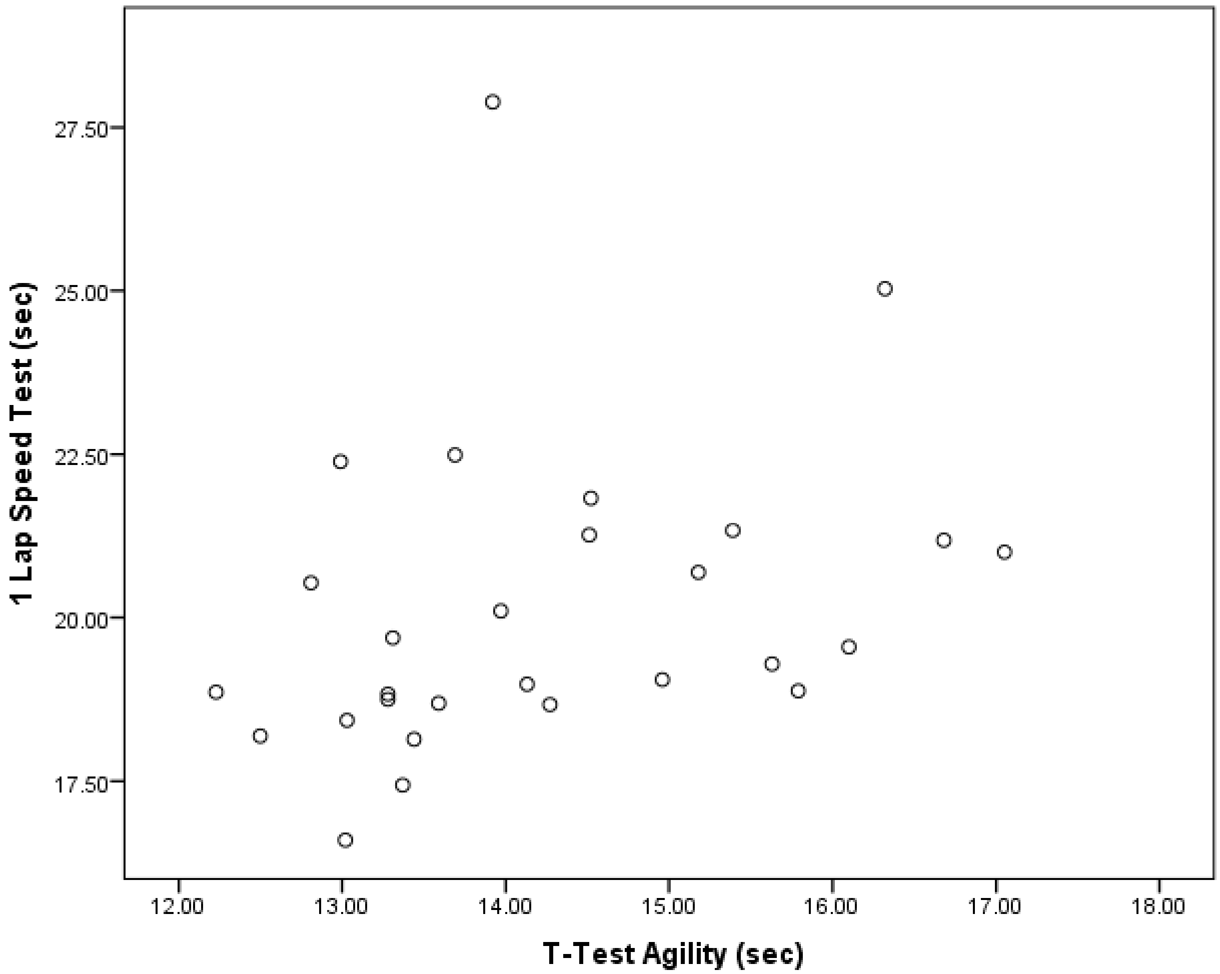


Figure 40: 1 Lap Speed Test and T-test of agility

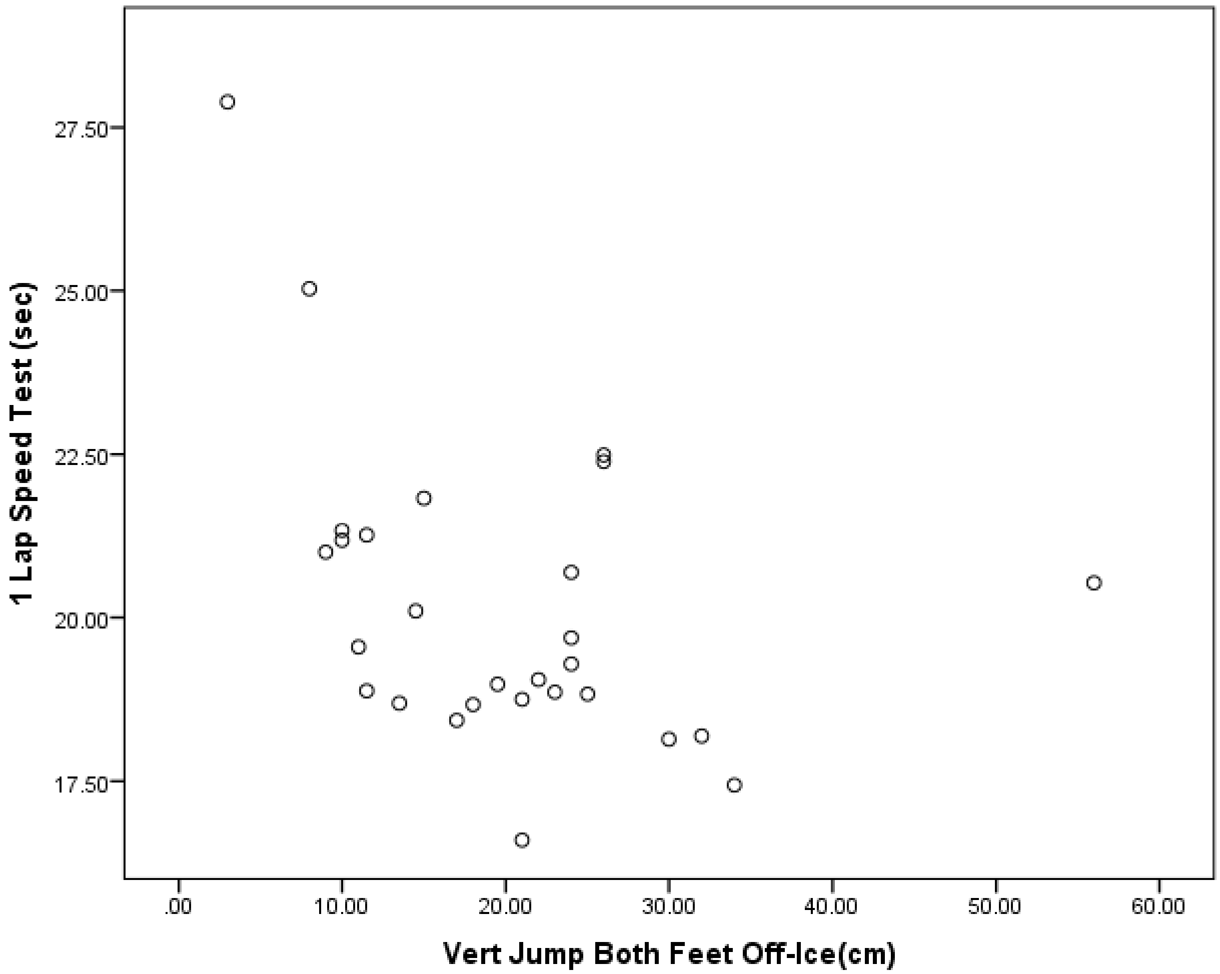


Figure 41: 1 Lap Speed Test and Vertical Jump performed off-ice

5.6 Conclusion

The purpose of this study was to examine the relationship between physical health-related fitness and skill-related fitness compared to on ice performance of developmental figure skaters. Results of the study show that skater who can land an axel jump are stronger skaters as determined by the 1-Lap Speed Test and required spin elements. The physical fitness tests showed that the axel group has much better balance on their landing foot. This also might related to the fear that skaters have when attempting the axel jump and skaters who have strong balance on their landing foot will likely have more confidence to attempt the axel jump. Balance is also related to spin ability and as the axel group performed better in all three spins at the $p<0.01$ level as well as balance with their eyes closed, balance is a critical component of physical fitness to developmental figure skaters. Results show that core strength is also a critical component at the $p<0.01$ level as determined by the one minute sit-ups and seated reach test. As well, the plank test showed that skaters must use strength and balance on their skating side for landing the jumps.

Muscular strength as measured by the vertical jump and grip strength tests showed that developmental figure skaters require some basic strength in the lower body (legs) but not a significant amount of upper body strength (arms) to land single rotation jumps or the axel. Skaters however do require muscular endurance in the lower body and core as measured by the timed-tuck jumps, sit-ups and plank tests. Off-ice conditioning for skaters should include muscular strength training, muscular endurance training, balance and flexibility at the developmental stages. Skater should spend adequate time training the physical abilities required to do the difficult skills during their off-ice sessions. Coaches and trainers should also consider the weight of and effect that the skates have on a skater ability for both balance and strength in terms of jumping ability. Further studies should investigate whether more physically fit skaters are able to pick up the more difficult skills in shorter time periods. As well, good jumpers need to be strong skaters and skaters should spend time improving their skating ability as well as their jump technique in lessons and practice time.

This was the first study to investigate the physical fitness of developmental figure skaters and to relate it to their on-ice performance of skills. Other studies have discussed the need for better off-ice training for figure skaters (Bower et al., 2010; Comuk & Erden, 2012; Ferrara & Hollingsworth, 2007; Fortin & Roberts, 2003; King, 2005; Kovacs et al., 2004; Mannix et al., 1996; McMaster et al., 1979; Skate Canada, 2010) and coach training and certification programs for figure skaters should include more off-ice fitness instruction for coaches as well as training them for assessments of physical fitness of skaters.

The study was limited by comparisons to mainstream child fitness programs used in schools and fitness programs because of the need for complicated equipment to perform those tests. Another area for future research is to determine if developmental figure skaters require more physical fitness in certain areas than other athletes or non-athletes in relation to figure skating being an early specialization sport.

CHAPTER SIX CONCLUSION

6.1 Research Questions Addressed

The main objective of the study was to investigate and examine the relationship between the physical fitness to on-ice performance of developmental figure skaters. The research shows that skill-related and health-related components of physical fitness may act as constraints on the acquisition of various figure skating skills (e.g., jumps, spins, and basic skating). The research suggests that balance, core strength and muscular endurance act as constraints on the acquisition of the axel jump. As well, skating ability as determined by a skater's speed and spinning ability are also constraints.

Agility did not prove to be a statistically significant constraint on the ability to perform and axel but was correlated to skater's speed on the ice. Vertical jump scores were also correlated to on-ice speed while Timed-Tuck jump scores correlated with the on-ice acceleration test showing a clear relationship between physical fitness and on-ice skating ability.

6.2 Deviations from Original Proposal

As mentioned earlier, the data from the spiral test was recorded incorrectly (the tester did not record the height of the standing leg) so it was removed from the comparisons. It was originally planned to be compared to the balance test results and the camel spin results to determine the effect of both balance and flexibility on the camel spin.

It was proposed that a minimum of 40 skaters were recruited. On the original testing day only 28 skaters were recruited which was enough to reach statistical power similar to Comuk & Erden if the skaters groups had been equal in numbers based on their ability to perform the axel or not. However, as only 2 skaters were successfully able to perform this skill at the original testing day (and this could not have been predicted), another testing day was arranged in a different skating region (the Vancouver Island region) to that no skaters could be retested. By contacting the coach a head of time, the researchers were aware that there were several skaters at this testing site that could successfully perform the axel. After the second day of testing, the axel group was increased to nine skaters.

Additionally, due to one more mistake by the researcher (recording of height and weight that was sent home accidently with the skaters personal result sheets and not recorded anywhere else), BMI could not be calculated and used for comparison to the results of this study or other studies.

Possible confounding data of training history was collected but was not useful information and some of the skaters and their parents were not sure exactly of hours trained or tests passed without their coaches or access to previous coaches.

6.3 Study Limitations

Skaters participating in the study may suffer from nervousness thus performing skills under their ability. To minimize this effect, the skaters performed the speed and acceleration tests first and were able to perform any test as many times as they wished (up to a limit) to assure their best performance is measured. No skater was required to perform a skill to the limit of attempt.

A skaters training age is of more significance then their actual age because of the time required to master basic skating before performing complex skills in skating. A questionnaire regarding training history was provided prior to commencing the physical fitness testing to account for variations in training age. However, as the physical fitness test results showed direct correlations with skaters' abilities, this data was not entered or analyzed. Also, the data collected was difficult to interpret because of the difference in training over the types of seasons and how participation in different sports could be quantified. As well, the parents who were filling out the forms were not able to accurately account for the child's training over many years.

Data was not collected regarding skater's maturation and peak height velocity as the average age was expected to be under 10 years old. As well, it was felt that this type of question might make parent feel uneasy and not give permission for their child to participate.

Another limitation was that there is very little normative data for children for the above mentioned physical fitness tests. Most of the literature lists physical fitness norms for adults only. No tests for coordination were chosen because of the lack of normative data and reliable tests for coordination and it is not an underlying component or constraint to the proposed skills for study.

For vertical jump testing, skaters may have differences in the strength of the dominant landing leg which many impact the results therefor testing will occur on both feet and then each foot singularly. As well, interference from the skating boots may have affected the vertical jump so a test of vertical jump with skates on was conducted as the final test to account for the influence that the skates have the height of the jump.

A pilot study was mentioned as a possibility but abandoned because of the requirement to get participants to commit to two days of testing.

6.4 Recommendations for Future Research

As it has been established that there is a significant relationship between the physical fitness capabilities of figure skaters and their ability to land an axel jump, a logical step forward would be to use a longitudinal intervention study where skaters in one group receive physical fitness training in the components described as constraints in this study while the control group does not receive any additional off-ice training in addition to their on-ice skill instruction.

Another possible area of future research would be to investigate the effect of fear on the acquisitions of the axel jump and whether it can be reduced by balance training to build confidence for skaters to acquire the jump quicker.

As research by Comuk & Erden (2012) showed that physical fitness has an effect on the acquisition of double axel jump, including upper body strength, more investigations on the physical fitness required for double jumps of just two rotations is warranted and to determine at what point does upper body strength become an important factor in elite figure skating.

6.5 Recommendations to Stakeholders

This research is provides an vital segment of knowledge for all figure skating coaches working with developmental skaters on axel jumps in how to best balance time in technical lessons with physical fitness training. All skating clubs should be ensuring that their skaters and members have access to fitness training programs to develop the required physical capabilities for the technical skills in skating. PSOs and NSOs in figure skating should put in more effort than to make arbitrary suggestions about the need for off-ice fitness training programs and develop better guidelines for clubs and coaches and even seminars and workshops on how to provide this need within their own club's and practice sessions. More time should be spent on properly training coaches to assess and develop training programs for their skaters. Coach developers and learning facilitators within these organizations should be given this information to pass on to new coaches and to develop better coaching manuals with the importance of each physical fitness component and its relationship to on-ice skill achievement.   Finally, through the above mentioned influence, skaters and parents may realize the importance of placing their children in programs that develop all the basic skills requirements, both technically and physically.

6.6 Final Words

Figure skating is a sport which requires a tremendous amount skill and physical fitness in order to compete not only at the highest levels but also to develop basic skills. Many coaches focus almost exclusively on skill training and ignore the significance of physical conditioning. It is essential to recognize the importance of a properly structured off-ice conditioning to improve on-ice performance. With a proper physical conditioning program, athletes can develop the necessary strength, balance, flexibility, and muscular endurance necessary to achieve higher levels of on-ice performance.

If more skaters are given the necessary training for their development, including off-ice conditioning programs, more skaters will reach success surrounding the axel jump and may participate in the sport for longer periods of time, increasing both participation, skill level, and revenue which is beneficial for all stakeholders within this sport.

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Appendix A: Skate Canada's Learn to Train Stage - LTAD

LEARN TO TRAIN

The second stage in Skate Canada's LTADM is Learn to Train. In this stage we begin to see more differences between females and males in terms of growth, development, and maturation. Thus, training and coaching adaptations are necessary specific to age and biological sex. Continued development of basic fundamental movements and skills as well as the introduction of more complex figure skating skills are essential.

The chronological ages of participants in this stage are:

	Female	Male
Learn to Train	7 – 11	8 – 12

Philosophy

In the Learn to Train stage skaters are encouraged to acquire a skill set that will allow them to reach the highest level of proficiency that their unique talent and commitment will allow. It is defined by technical development rather than chronological age. There is a free skating bias at this stage as skills learned in free skating will transfer easily to the other disciplines. Technical development is the defining characteristic of this stage. All other development supports and accommodates technical development. Aptitude in other areas such as performance and mental training skills may be identified and should be introduced but should not replace skill acquisition. The volume of training in the Learn to Train stage may not be any greater than others but the range of skill acquired and personal growth attained is substantial.

General Objectives

- To increase the commitment level of athletes to our sport as demonstrated through increased yet effective training time
- To develop the language and rules of figure skating
- To develop the ability to practice/train in different ways (i.e. private and group lessons, as well as independently)
- To develop and consolidate basic sport specific skills while continuing to develop motor skills (agility, balance, coordination, rhythm, time/space orientation, speed, dexterity) and control of movement
- To acquire and demonstrate a good understanding of the mechanics of jumping and spinning
- To develop some understanding of artistic training, under the umbrella of technical training. Artistic knowledge is relative to the technical proficiency and age of skaters
- To introduce conditioning, off-ice technical jumping skills and fundamental mental skills including concentration, self-motivation, visualization, relaxation, positive self-talk and goal setting
- To create awareness and enthusiasm for the various testing and competition opportunities available to athletes in Learn to Train
- Introduce ancillary capacities (warm-up, hydration, cool-down, stretching, etc.)

Windows of Optimal Trainability

The following physiological factors must be introduced and developed through specific programming and coaching and in accordance with age and gender:

- ✓ Skills ("golden age": 8-12)
- ✓ Speed (female: 6-8; male: 7-9)
- ✓ Suppleness (Flexibility) (female/male: 6-10)
- ✓ Stamina (at the onset of PHV-peak height velocity)

Guiding Principles

In order to allow athletes to develop and acquire the skills outlined, the Learn to Train stage must:

- ✓ Focus on technical training. Artistry, choreography and musicality should come under the umbrella of technical training
- ✓ Account for individual training needs and talents. The frequency of practice and number of repetitions must be high enough to ensure learning; however, this will be case-by-case and skill-by-skill. It is not possible to assign a definitive number suitable for all skaters
- ✓ Adhere to the idea that 70% success rate is required for learning to occur
- ✓ Adhere to the principal that the athlete should spend more time training than competing
- ✓ Include the monitoring by coaches of Peak Height Velocity (PHV) and windows of optimal trainability, flexibility, speed, endurance and strength according to age and biological sex
- ✓ Coaches should be knowledgeable on growth, development and maturation process
- ✓ Introduce single periodization (i.e. seasonal and multi-year planning)
- ✓ Account for the social development of each skater through the ways in which programs are offered and delivered by clubs and coaches
- ✓ Provide resources that include parent education
- ✓ Include regular assessments and evaluations which are done primarily by the coach and which include constructive and clear feedback to both the athlete and her/his parent(s)/guardian(s)

Mission of the Coach

The mission of the coach is to teach the basic sport specific skills and elementary artistic expression essential to participate in the chosen activity. Coaches must also introduce physical conditioning and fundamental mental skills. Sport specific skills are coupled with motor skill development. Coaches should continue to encourage children to be involved in several sports in the early part of this stage.

While the skater's parent(s)/guardian(s) will act as her/his manager in this stage, the coach will act as the director of development. Coaches have the option to train as a technical specialist but are also responsible for regular assessments and evaluations of a skater's progression. Coaches have the ability to teach/transfer information in a manner appropriate to age, gender and an ability to teach good skill technique.

All coaches potentially train world-class athletes but simply at a different stage of their development. Therefore, coaches of athletes in this stage of development need to understand figure skating at a level far beyond that at which their skaters may currently perform so they can provide relevant training at the appropriate time in preparation for the skater's future. Coaches should always be able to provide a rationale for why they are teaching a certain skill or concept and how they are using a skater's time.

Coach Education and Certification

The standard of coaching at this level does matter and it will impact future development. It is essential that coaches provide the best available technical training and are knowledgeable on growth, development and maturation.

NCCP Instruction–Intermediate/
Competition-Introduction

SPORT SPECIFIC SKILLS

This chart represents the skills participants should be able to demonstrate or show a relative mastery of the skills dependent on the volume of training at the exit point of Learn to Train. For most athletes, growth spurts will occur during this stage of development. When this is occurring, skills already learned should be maintained. New skills should not be introduced during the growth spurt and competitions should be reduced so as to avoid negative results due to the fast physical changes.

	Females (7-11) and Males (8-12)
Motor Skills	Continued development of balance, agility and coordination demonstrated by: • Developing awareness of the relationship between speed and lean • Kinesthetic awareness: repeating shapes and pathways; following movement through space; recognizing steps and being able to describe them, movement combinations, perception of movement in self, opposition of legs, arms and torso • Use of the blade and interface with the ice — changing the balance point (gliding, rocking, sliding), multiple turning/twisting and leaning tasks, use of the toe pick, production and manipulation of force • Understanding the movement of the joints — backbone, hip joint, head, legs and arms, rotational movement of the spine line • Skater's perception of their own body rhythm
Technical	**Edges** • Able to perform well-controlled strong, fast edges including a back change of edge • Lean, depth of curve, and control demonstrated on both feet and all edges **Turns** • Able to perform step sequences with simple, clean edges and turns • Demonstration of multiple turns executed with flow in both directions and on both feet • Multiple turns, brackets, counters, choctaws and loops are introduced and developed • Skaters should begin learning the rocker mechanism **Stroking** • Demonstration of a very good crosscut technique including push with the blade, acceleration, maintenance of speed and flow and body carriage • Able to vary the timing of crosscuts with ease in both directions both forwards and backwards **Jumps** • Able to perform single jumps with speed and control • Able to execute single Axels and two or more clean double jumps • Developing double/double combination • Some understanding of how doubles will become triples • Consistent and correct air and landing position **Spins** • All forward and backward spinning positions and changes of positions well executed • Able to perform combination spins that include all three basic positions • Demonstration of some basic position variations with minimal to no loss of speed and control **Field Moves** • Ability to perform both supported and unsupported spiral positions as well as other field moves (i.e. spread eagles, Ina Bauers, pivots, etc.) • Demonstrated ability to maintain speed and flow in basic field movement positions • Learning to perform simple field moves in transitions
Artistic	• Able to demonstrate an understanding of beat, tempo, dynamics and simple rhythmic patterns through movement • Introduce various musical themes and instill an appreciation of the differences • Introduce use of the full body and different levels of movement (i.e. high, medium, low) • Participation in ballet and other types of dance training in addition to other off-ice classes

General Skills

General skills (i.e. physiological, psychological, and social) are developed through involvement in the sport and lend themselves toward the overall development of the individual.

Age	Females (7-11) and Males (8-12)
Physiological	• Increased development of motor skills, speed and suppleness • Ability to perform basic strength training movements using own body weight, medicine balls, and stability balls • Beginning to demonstrate appropriate levels of stamina

Psychological	• Acquired basic knowledge of fundamental mental skills (i.e. what they are and what their function is) including:
	  • Focus and anxiety management strategies
	  • Goal setting
	  • Mental preparation for practice, testing and competition
	  • Positive self-awareness/self-concept

Social	• Increased knowledge of the rules and ethics of sport • Some ability to act as both leader and follower and demonstrated ability to cooperate with others • Ability to take risks and/or meet challenges presented • Learning to measure success through self-evaluation • Demonstrated understanding that education remains the most important priority

The following information outlines the ideal amount of time spent on and off the ice at this stage of development. It is imperative that coaches, parents, and support team members recognize that hard training of poor skills thwarts future development.

On-Ice Training

Due to the significant development that occurs in the Learn to Train stage, the table below outlines a progression from time of entry into the stage to point of exit. Note that ice time more than doubles from entry to exit point within this stage. The progression to greater amounts of on-ice training time will occur early in the stage in most cases. That said, it will also be dependent upon specific athlete circumstances and training needs.

Entry	**Session length:**	• 45 to 60 minutes on-ice, with 15 minute off-ice warm-up prior • Maximum one session/day
	Days/week:	• 2 to 4 days/week
	Weeks/year:	• Minimum: 20 weeks/year • Ideal: 30 to 40 weeks/year
Exit	**Session length:**	• 45 to 60 minute on-ice, with 15 minute off-ice warm-up prior • 1 to 2 sessions/day
	Days/week:	• 4 to 5 days/week
	Weeks/year:	• Minimum: 40 weeks/year • Ideal: 44 weeks/year

The relative amount of time skaters may practice various activities is expressed below as a percentage of their total ice time at the entry and exit points of the Learn to Train stage. Again, individual training needs will vary with each skater.

Skills/ Activities	Entry	Exit
Technical	**100%**	**60%**
	This includes: • Edges/Turns • Jumps • Spins • Stroking • Field movements	This includes: • Edges/Turns • Jumps • Spins • Stroking • Field Movements
	Priority given to edges/turns, jumps and spins	Priority given to jumping
Program Components		**40%**
		This includes: • Creative Movement • Ice Dancing • Program Development • Other (as applicable)
		Priority given to program development

Off–Ice Training

In the Learn to Train Stage, skaters should participate in a variety of other sports and activities to become better athletes and more well rounded skaters in both body and mind. As in the Learn to Skate stage, the specific types of activities will depend on the specific socio-cultural context of the athlete but coaches, parents, and clubs are encouraged to explore the different opportunities that exist in their communities. That said, at this stage of development more sport-specific activities such as off-ice technical jumping classes should be introduced to help with body development and awareness and the understanding of movement patterns. It is important to note that the proportion of on-ice to off-ice activity is also seasonal and subject to periodization. Knowledge of the intentions behind warm-up, cool-down, stretching, nutrition, hydration, and rest and recovery should be encouraged.

At point of entry into Learn to Train, skaters should be participating in one to two hours of sport-specific off-ice activity each week, for 20 to 40 weeks of the year. At point of exit from Learning to Train, skaters should be participating in three hours of formalized off-ice activity each week, 44 weeks of the year.

Competition [4]

At the point of entry and the earlier phases of the Learn to Train stage, emphasis should remain on technical development and training time, with a minimum of competition. At the entry point, one competition per year progressing gradually to between two and four is sufficient. Four to six competitions per year is more than adequate at the exit point of this stage. These competitions will be a combination of element and skill performance and programs, with a focus more on skills in the earlier stages of development.

As skaters progress through the Learn to Train stage, a program will be introduced for the first time with choreography tailor-made for the athlete. Performances will include the presentations of programs; however, skill presentations should remain the primary focus in this stage of development.

Events at the club level remain a priority with a focus on fun, enjoyment, camaraderie, and a sense of personal accomplishment. Rewards might include praise in the form of positive and constructive verbal and written feedback, badges, ribbons, or medals, the opportunity to attend clinics or seminars, public displays of congratulations (e.g. using the local media or a bulletin board in the facility) and, in the latter stages, completion of tests within the Skate Canada STARSkate program.

Evaluation at this level is still primarily the responsibility of the coach although evaluators, judges, and technical specialists will begin to play a role towards the exit point of the stage. The established guidelines for Well Balanced Programs within the Cumulative Points Calculation (CPC) system must direct the choreography and performance of programs.

[4] See Appendix C for the Stages of Athlete/Participant Development Overview.

Appendix B: Consent Form

Examining the Relationship between Physical Fitness and Performance in Developmental Figure Skaters.

Figure Skater Physical Fitness and Performance

Principal Investigator: Dr. Phil Ainslie, PhD - UBC

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Principal Investigator: Dr. Phil Ainslie, PhD - UBC

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Co-Investigator(s): Dr. Lauren Couture, PhD – UBC
Dept. of Kinesiology and Physical Education

Regan Taylor, MSc Candidate – UBC

[redacted]

Appendix C: Skater information Form

THE UNIVERSITY OF BRITISH COLUMBIA

UBC

Figure Skating Physical Fitness and Performance Study

Skating History and Information **Participant #__________**

Personal Information

Full Name: ____
Last *First*

Skate Canada #: ____

Birth Date Day/Month/Year): ______________ Comp Level: ______________________

Highest Tests Passed: ____

Please indicate tests passed in all disciplines (Freeskate, Dance, Skills, Interpretive)

On IceTraining History

Age started skating? ______________________ Day/Month/Year ______________________

Age started competitive skating (figure skating?) ______________________ Day/Month/Year ______________________

hours on ice training per week ______________________ # weeks skating per year ______________________

years training at this intensity?

 # Off-IceTraining History

Do you participate in other sports? : **O Yes** **O No** **Please list the sports that you participate in the space below:** ______________
Last

Please explain your other sport participation over the past 5 years.

Do you participate in off –ice training? :**O Yes** **O No** **Do you have an off ice spinner that you use?** O Yes O No ______________
Last

Thank you for your time completing this questionnaire and participating in this study.

Appendix D: Health Questionnaire

THE UNIVERSITY OF BRITISH COLUMBIA

OKANAGAN

Health Screening Questionnaire

Thank you for considering participation in our study. We would be most grateful if you could take the time to complete this questionnaire in relation to the health of your child, which should take about 5 minutes to complete.

Please return this completed questionnaire with the consent and assent forms when you visit the laboratory.

Completing the questionnaire

- This questionnaire should be completed by the **main caregiver** for the child.
- Please answer the questions in relation to **your child's current health.**
- Please indicate your answers by ticking the relevant box or by writing your answer in the space provided

Confidentiality

All information about you and your child will be kept in the strictest of confidence. Your responses will only be seen by members of the research team and will be made anonymous.

Why we are collecting this information

The purpose of this form is to ensure we provide every child with the highest level of care. For most children, exercise provides an opportunity to have fun and promotes the basis for good health and an enhanced quality of life for the future. However, there are a small number of children who may be at risk when exercising. There are some health conditions, such as of heart, blood vessel, metabolic (e.g., type 1 diabetes) or lung and breathing problems or diseases, that make participation difficult or unsafe and we need to be sure all the children participating in our study are able to complete the procedures safely.

Contact us

If you have any questions about the study during your participation you may contact Regan Taylor at (604) 309-5557.

Appendix E: Form for use for recording off ice testing data

THE UNIVERSITY OF BRITISH COLUMBIA

INDIVIDUAL ATHLETE FITNESS TEST RECORD SHEET

SIGNED CONSENT: Yes ☐ ☐

DATE TIME

ATHLETE AGE

Group Participant #

BODY MEASUREMENTS:

HEIGHT (cm) ________
WEIGHT (kg) ________

FLEXIBILITY TESTS:

SIT AND REACH: ________cm

STANDING SPIRAL: ________cm

BALANCE: STORK STAND

Left: ________s Right: ________s eyes OPEN
Left: ________s Right: ________s eyes CLOSED

AGILITY TESTS:

Measure to tenth of a second.

HEXAGON TEST CCW: ________s (1)

HEXAGON TEST CW: ________s (1)

T-TEST: ________s

Timed Tuck Jumps: ______________

(number of completed jumps)

VERTICAL JUMP TESTS:

No skates:

VERTICAL JUMP HEIGHT (2 FT): ________cm

VERTICAL JUMP HEIGHT (R FT): ________cm

VERTICAL JUMP HEIGHT (L FT): ________cm

Skates on:

VERTICAL JUMP HEIGHT (2FT): ________cm

VERTICAL JUMP HEIGHT (RFT): ________cm

VERTICAL JUMP HEIGHT (LFT): ________cm

STRENGTH:

GRIP STRENGTH (Right): ________
GRIP STRENGTH (Left): ________

STRENGTH ENDURANCE:

ONE MINUTE PUSH-UPS: ________ # COMPLETED

ONE MINUTE SIT-UPS: ________ # COMPLETED

PLANK (Right): ________s
PLANK (Left): ________s

Appendix F: Form for use for recording on ice testing data

THE UNIVERSITY OF BRITISH COLUMBIA

INDIVIDUAL ATHLETE FITNESS TEST RECORD SHEET

SIGNED CONSENT: Yes ☐ ☐

DATE **TIME**

ATHLETE **AGE**

Group **Participant #**

ON ICE ONE LAP SPEED TEST:

ASSESSOR 1 ________
ASSESSOR 2 ________
ASSESSOR 3 ________
AVERAGE: ________

Measure to tenth of a second.

ACCELERATION TEST:

ASSESSOR 1 ________
ASSESSOR 2 ________
ASSESSOR 3 ________
AVERAGE: ________

Measure to tenth of a second.

JUMP ASSESSMENT:

AXEL JUMP:
ASSESSOR 1 ________________
ASSESSOR 2 ________________
ASSESSOR 3 ________________
 # ROTATION: ________________
AIR POSITION QUALITY: ________________

SPIN ASSESSEMENTS:

BACK SPIN:
ASSESSOR 1 ________________
ASSESSOR 2 ________________
ASSESSOR 3 ________________
 # ROTATION: ________________
POSITION QUALITY: ________________

NOTES:

SIT SPIN:
ASSESSOR 1 ________________
ASSESSOR 2 ________________
ASSESSOR 3 ________________
 # ROTATION: ________________
POSITION QUALITY: ________________

NOTES:

CAMEL SPIN:
ASSESSOR 1 ________________
ASSESSOR 2 ________________
ASSESSOR 3 ________________
 # ROTATION: ________________
POSITION QUALITY: ________________

NOTES:

Appendix G: Initial Recruitment

a place of mind
THE UNIVERSITY OF BRITISH COLUMBIA

Examining the relationship between physical fitness and performance in developmental figure skaters

While physical fitness of elite figure skaters has been shown to impact their performance, little is known about the physical requirements of developmental figure skaters. Many skaters leave the sport during the developmental stage of mastering the axel jump and the basic spins. Some skaters may lack the physical fitness requirements to perform certain skills and experience a sense of frustration and loss of self-esteem when they can't perform the skills. We will be investigating the relationship between physical fitness and the ability to perform certain skills in developmental figure skaters. We are inviting healthy girl figure skaters between the ages of 6-14 years to participate in this study, which will help us to understand how physical fitness is related to performance of skills in figure skaters. We are currently inviting girls ages 6-14 years who are currently in STAR 2, STAR 3, STAR 4 and STAR 5 categories The study involves a one day testing event that will take approximately 2.5 hours to complete. The physical fitness tests will be divided into two sessions of 5 tests that will take approximately 30 minutes to complete. In between the two rounds, the participants will be given a 30 min break. After another 30 minute break, the skaters will finish with their on-ice performance tests that will take approximately 30 minutes to complete.

If you would like to find out more about participating in this research study, please contact Regan Taylor by email [redacted]