ABSTRACT

INJURY PROFILES AND OFF-ICE JUMPING ANALYSIS OF FEMALE SYNCHRONIZED ICE SKATERS

by Alexandra Michaele Smith

Synchronized skating is the newest division of figure skating and injury research in this division is minimal. This study investigates the prevalence and incidence of injuries in synchronized skating, and compares off-ice jumping data between synchronized skaters across jumping level. Retrospective questionnaires were completed by 58 synchronized skaters across 5 levels. Sixteen collegiate and open collegiate level skaters completed 3 off-ice jumping exercises on a force plate. Of the 51 reported synchro injuries, 35 (68.6%) were acute injuries, with injuries to the head and spine being the most prevalent. There was a significant difference in injury prevalence found across moves-in-the-field test levels (p=.018), and between Jackson and Edea skating boot brands (p=0.039). There was a significant difference in stiffness between jumping groups during left leg (p= 0.007) and right leg (p=0.003) metronome hopping. Acute injuries may be more prevalent in synchro due to the multiple skaters on the ice. Edea boots’ stiffness may lead to injury, and synchro skaters may benefit from wearing different boot types. Lastly, synchronized skaters with higher jumping ability seem to be less stiff, which could be an indication of a quicker release. Further research is needed that includes different synchro levels and rotational jumping.
INJURY PROFILES AND OFF-ICE JUMPING ANALYSIS OF FEMALE SYNCHRONIZED ICE SKATERS

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Dedication

This project is dedicated to my parents, Caralea and Steve Smith, for the hundreds of hours spent at various ice rinks and the thousands of dollars spent on training. The constant encouragement of both my academic and athletic pursuits has not gone unnoticed and the unwavering support has made everything possible.

Also to Jordan, my best friend of 15 years. We’ve experienced middle school, high school and college together, as well as over a decade of competitive skating, and there is no one that knows me better than you. Thank you for keeping me grounded over the many years and being a constant source of support.
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I would also like to thank all the skaters that participated in the study, many of whom were extremely enthusiastic about the project and excited over the growing interest in the sport of synchronized skating. I would like to specifically thank the Miami University Collegiate Varsity Synchronized Skating Team and the Miami University Open Collegiate Synchronized Skating Team and their coaches for their cooperation and willingness to take time out of their days to come to the lab and help complete this project.

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1. Introduction

1.1 Introduction to the Research Problem

Synchronized skating is the fastest growing figure skating discipline in the United States, with over 9,000 active synchronized skaters in 2016. The first World Synchronized Skating Championships was held in 2000, and since then, participation and viewership has grown exponentially (US Figure Skating Association, 2016). Researchers have studied freestyle (‘singles’) skating, pair skating, and ice dancing extensively, but there has been little research on synchronized skating, with the only research being conducted on senior-level teams.

There are large, fundamental differences between synchronized skating and the other traditional disciplines of figure skating. Compared to freestyle and pair skating, synchronized skating has very few jumps, requires intricate footwork, and consists of multiple skaters on the ice simultaneously. Synchronized skating also involves skaters passing into and out of complex, patterned elements at high speeds, which adds potential for contact injuries. These fundamental differences between the skating disciplines could affect the nature and incidence of injuries in these athletes. There has also been no research on how the jumping background of synchronized skaters would affect their landing forces. Synchronized skaters who do not have an extensive jumping background may record lower muscular power, flight time, time to stabilization, and peak vertical ground reaction forces when landing, when compared to synchronized skaters who have a higher level jumping background.

In this study, demographic and injury data of 58 of synchronized skaters of various age, skill level, and activity level will be collected and analyzed. Countermovement jumping data will be collected on a force platform from two college-aged teams to be analyzed and compared.

1.2 Synchronized Skating

1.2.1 Origin and History of Synchronized Skating

Synchronized skating is the newest division of figure skating, with the first team formed in 1956. Dr. Richard Porter is commonly referred to as the ‘father of synchronized skating’, as he created the first team, the Hockettes, in Ann Arbor, Michigan. At its inception, synchronized skating was called ‘precision skating’ and was more akin to the famous dance team The Rockettes, the Hockettes namesake, than a figure skating team. The Hockettes performed during
intermissions of the University of Michigan’s hockey games, as competitions had not yet been created for this division of skating.

During the 1970s, interest in synchronized skating skyrocketed in North America, and the first synchronized skating competition was held in Ann Arbor, Michigan, which saw teams from the United States and Canada participate. It was during this time that the sport rapidly evolved, with teams adding in higher risk elements from other divisions of skating, such as jumps, lifts, and spins, while performing with higher speeds and more complicated transitions and elements.

Due to the exponential growth in the United States, the first United States Synchronized Skating Championship, then called the “U.S. Precision Championships” was held in 1984, in Bowling Green, Ohio, with the Fraserettes winning the inaugural event. In 1989, Finland hosted the first official international synchronized skating competition. Five years later, in 1994, the International Skating Union (ISU) officially recognized synchronized skating as the fifth discipline of figure skating, and, in 2000, the ISU held the first ISU World Synchronized Skating Championship, where Finland’s Team Surprise won the gold medal.

1.2.2 United States Synchronized Skating in Recent Years

The ISU Synchronized Skating World Championships has been held every year since its inception. In 2007, the United States won its first senior world medal when the Miami University Senior Varsity Synchronized Skating Team won the silver medal, defeating two Canadian teams, two Finnish teams, and the higher-ranked U.S. team. In 2010, the U.S. hosted the 11th annual ISU Synchronized Skating World Championships in Colorado Springs, Colorado, where 23 teams from 18 countries participated. The Haydenettes, out of Boston, Massachusetts, have been the most successful senior-level synchronized skating team in the United States, winning 25 national titles and earning five bronze medals at the World Championships.

Along with national and international synchronized skating growth, U.S. collegiate synchronized skating has also quickly grown since its inception in 1997. The debut of the collegiate program saw teams from only three colleges participate. In 2016, almost twenty years later, there were 37 collegiate teams competing in one of two levels: collegiate or open collegiate, as seen in Figure 1. Miami University and Adrian College have also competed in the international junior and senior levels, the highest levels achievable, with one team being a member of Team USA.
Many collegiate synchro teams fall under the ‘club sports’ banner, which are student run organizations that receive no monetary support from the United States Figure Skating Association (USFSA). However, many high ranked club teams receive funding from their universities. Along with club synchronized skating teams, there are three fully funded varsity synchronized skating programs in the United States: Miami University, Adrian College, and Lindenwood University.

**Figure 1** Total Number of Collegiate Synchronized Skating Teams Registered in the United States

![Graph showing the total number of collegiate synchronized skating teams registered in the United States from 1997 to 2016.](image)

Despite it’s overwhelming growth and participation, synchronized skating is not an Olympic event, which has caused many casual figure skating fans to negatively view the discipline. In 2016, a social media movement, #whyntsychro, was created to help gain visibility and support for the inclusion of the discipline in the 2018 PyeongChang Olympics. A proposal was created and the International Olympic Committee (IOC) considered the proposal, but ultimately did not approve the inclusion. However, five international senior-level teams performed their free programs as a scored exhibition at the 2016 World Figure Skating Championships in Boston, MA. This was considered a huge step in the progress of legitimizing the discipline, as the ISU World Synchronized Skating Championships is a separate event from the ISU World Figure Skating Championships. There are hopes that logistical and personnel
issues will be resolved, and synchronized skating will join the line up in the 2022 Beijing Olympics, either as a demonstration sport or as a fully recognized sport.

1.2.3 United States Synchronized Skating Levels

Team skating levels are determined by testing level, age, and skill of the participants. Each level has a limit on the number and age of skaters allowed, what competitions teams can participate in, whether a team competes one or two programs in a competition, and whether the 6.0 or International Judging System (IJS) scoring system is used.

The USFSA currently has four different tiers of competitive synchronized skating levels:

1. Developmental levels: Synchro skills 1, 2, 3; Preliminary, Pre-Juvenile, Open Juvenile
2. Competitive levels: Juvenile, Intermediate, Novice, Junior, Senior
3. Collegiate levels: Open Collegiate, Collegiate
4. Adult levels: Adult, Open Adult, Masters, Open Masters.

1.2.4 Synchronized Skating Level Definitions

<table>
<thead>
<tr>
<th>Level</th>
<th># of skaters</th>
<th>Age of skaters</th>
<th>Stipulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Juvenile</td>
<td>8-16</td>
<td>&lt;13</td>
<td>Passed pre-juvenile MIF&lt;sup&gt;b&lt;/sup&gt; test</td>
</tr>
<tr>
<td>Intermediate</td>
<td>12-20</td>
<td>&lt;18</td>
<td>Passed juvenile MIF test</td>
</tr>
<tr>
<td>Novice</td>
<td>12-20</td>
<td>&lt;16&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Passed intermediate MIF test</td>
</tr>
<tr>
<td>Junior</td>
<td>12-16</td>
<td>13-18</td>
<td>Passed novice MIF test</td>
</tr>
<tr>
<td>Senior</td>
<td>16</td>
<td>&gt;14</td>
<td>Passed junior MIF test</td>
</tr>
<tr>
<td>Collegiate</td>
<td>12-20</td>
<td>-</td>
<td>Passed juvenile MIF test; must be enrolled in college or degree program as full time student</td>
</tr>
<tr>
<td>Open Collegiate</td>
<td>8-16</td>
<td>-</td>
<td>Must be enrolled in college or degree program as full time student</td>
</tr>
<tr>
<td>Adult</td>
<td>12-20</td>
<td>&gt;20&lt;sup&gt;d&lt;/sup&gt;</td>
<td>Passed one of the following tests: preliminary MIF, adult bronze MIF, preliminary figure, or preliminary dance</td>
</tr>
</tbody>
</table>

<sup>a</sup> Age as of July 1<sup>st</sup> preceding the season,  
<sup>b</sup> MIF: ‘Moves in the field’ test;  
<sup>c</sup> Exception of four skaters who may be 16 or 17;  
<sup>d</sup> Exception of four skaters who may be 18, 19, or 20;  
<sup>e</sup> All teams may have a maximum of four alternates on roster
1.3 Objective of Research

The objective of this research was to identity and evaluate injury data and off-ice jumping data to identity potential injury risk factors unique to synchronized skaters. The results of this study could be used to develop preventative strategies to potentially lower injury rates.

1.4 Specific Aims of Research

The specific aims of this research were:

1. To compare injury prevalence and incidence rate of synchronized skaters across multiple variables of age, skating level, experience, practice time, and equipment used.
2. To develop a profile of potential injury risk factors in female synchronized skaters.
3. To compare off-ice jumping data (muscular power, flight time, peak vertical ground reaction force, time to stabilization, stiffness) between collegiate synchronized skaters with and without high level individual freestyle skating skills.

1.5 Significance of Research

Synchronized skating is the fastest growing discipline of figure skating and is unique from the four main disciplines of figure skating. In 1984, only 38 teams participated in the US Synchronized Skating Championships. In the 2015-2016 season, 600 synchronized skating teams were registered in the United States, with over 9,000 synchronized skaters active throughout the country. With the number of participating athletes growing every year, knowledge on the unique injury risk factors and biomechanics of synchronized skating is necessary to ensure that skaters, parents, and coaches have the best knowledge available to help keep the athletes healthy by potentially creating new ways of lowering injury risk.
2. Current Knowledge

2.1 Injury Epidemiology

Epidemiology is defined as “the study of the distribution and determinants of health-related states or events, and the application of this study to the control of diseases and other health problems” (World Health Organization, 2014). An epidemiological perspective can be taken when studying sport injury, as these injuries are not random, unique to a defined population, and require specific and intentional interventions to reduce burden. Since athletic injuries are not seen as random, certain characteristics can be studied and casual factors of injury may be uncovered.

Prevalence and incidence are two measures commonly used in epidemiology. Prevalence refers to the proportion of individuals in a population who have been affected by a disease. Prevalence can be further broken down into ‘point prevalence’ and ‘period prevalence’, which is the proportion of the population that has the condition at a precise point in time or during a defined period of time, respectively. Prevalence can be calculated as the number of injuries (or “cases”) reported divided by number of people in the population over a defined period or point in time (Knowles, Marshal & Guskiewicz, 2006).

Incidence refers to the number of new injuries that occurred over a specific time span, such as a month, year, or competitive season. In epidemiological sport injury studies, incidence rate has been measured in the context of person-time risk, which takes exposure to risk into account and is therefore a more accurate measure. Incidence rate is found by dividing the number of injuries by the number of athlete-exposures. Athlete-exposures is found by multiplying the duration, in hours, of exposure by the number of athletes. This number is then multiplied by the amount of exposures that occur in the period of time being studied. Incidence has increasingly been reported as the number of injuries per 1000 hours, which contributes to the generalizability and comparison across sports (Phillips, 2000). It is important to understand the distinction between incidence and prevalence. Prevalence tells how widespread the injury or disease is, whereas incidence shows the rate of occurrence of new cases, and is a more accurate measure of risk.

The term ‘risk factor’ refers to any characteristic or variable of an athlete or sport that increases the likelihood of sustaining an injury. Risk factors are divided into two categories: intrinsic and extrinsic. Intrinsic risk factors are internal, athlete-related factors such as flexibility,
age, and previous injury. Extrinsic risk factors are external, environment-related factors such as sport participation, equipment, coaching, and playing surface (Frisch, Croisier, Urhausen, Seil, & Theisen, 2009). Relating injury rates and risk factor variables may uncover a correlation that, with further specific investigation, can lead to a potential causal link.

The ‘burden of injury’ can be defined as the impact of the injury on the athlete or athletic team. The burden of injury is usually determined by calculating the amount of time missed due to injury. This can be broken up to calculate the burden of a specific type of injury, during specific events, or over a period of time. This data can then be used to determine which type of injuries have the greatest negative impact on the sport or athlete as a whole, and then, by extension, can help uncover which specific characteristics lead to the greatest impact.

Epidemiological studies related to figure skating injury collection most commonly involve questionnaires and interviews of skaters in retroactive studies. Retroactive studies are commonly utilized because many years of data can be collected directly from the athletes, which can include first-hand accounts and details. Cross-sectional medical evaluations are another common method of figure skating injury collection. Medical evaluations involve researchers conducting medical examinations on skaters’ current injuries. Cross-sectional evaluations are very useful because they provide in depth data collection and analysis of injuries and can be more accurate than athletes attempting to recall details of injuries from years past.

2.2 Figure Skating Jump Performance

2.2.1 Jumping in Singles and Pair Skating

In recent years, there has been an exponential increase in jumping difficulty in competitive men and ladies singles skating. The ‘quad revolution’ in men’s skating has led to an increase in injuries leading up to the 2018 PyeongChang Olympics. Many figure skating analysts, former skaters, and fans are calling for a judging system change that puts less emphasis on jumps by either lowering the base value of quad jumps or by limiting the number of quad jumps allowed in each program (Hersh, 2017). This backlash is due to the injuries that are attributed to the over-practice of quadruple jumps, especially by men who are not technicians and are scrambling to catch-up to the high-level jumpers, sometimes by attempting quadruple jumps they cannot land, solely to get points for the attempt.
Ladies single skating has also gone through a jumping revolution in the past decade. In the 2006 Torino Olympics, only five triple-triple jump combinations or sequences were attempted by any ladies skater in the singles competition. Comparatively, there were 35 triple-triple jump combinations attempted in the 2018 PyeongChang Olympics, as all top skaters needed a triple-triple combination jump to be truly competitive. The full breakdown of jump attempts in the Olympics is displayed in Table 2.

In 2018, American Mirai Nagasu landed a triple axel at the 2018 PyeongChang Olympics, and was only the third lady in history to land this jump at the Olympics. In the same year, 13-year-old Russian Alexandra Trusova landed two quadruple jumps in her free program at the Junior World Championships, becoming the only junior lady to land a quadruple jump in competition, and only the second lady in history. These feats have led to many figure skating analysts questioning what these jumps are doing to the hips, knees, and ankles of young, developing skaters, and whether the outcome of landing these jumps and winning medals is worth the risk.

Table 2 Total Number of Attempted Jumps in the Olympic Men and Ladies Singles Event

<table>
<thead>
<tr>
<th></th>
<th>2006 Torino</th>
<th>2010 Vancouver</th>
<th>2014 Sochi</th>
<th>2018 PyeongChang</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Men</strong> (quadruple jump attempts)</td>
<td>20</td>
<td>15</td>
<td>40</td>
<td>69(^a)</td>
</tr>
<tr>
<td><strong>Ladies</strong> (triple-triple jump attempts)</td>
<td>5</td>
<td>16</td>
<td>26</td>
<td>35</td>
</tr>
</tbody>
</table>

\(^a\) 5 different men attempted ≥3 quadruple jumps in one free program

Jumping is also included in the pair skating division, both as side-by-side jumps, where the partners complete jumps in synchronization, and throw jumps, where the male partner throws the female partner into a jump. Each senior level pairs team is required one double or triple throw jump and one double or triple side-by-side solo jump in the short program, and two different throw jumps, one solo side-by-side jump, and one side-by-side combination or sequence in the free program. Much like the singles division, pair skating has seen an increase in the difficulty of jumps attempted. At the 2018 PyeongChang Olympics, Canadian pair Meagan Duhamel and Eric Radford landed the first clean quadruple throw jump in Olympic history.
2.2.2 Jumping in Synchronized Skating

Synchronized skating does not see the jump difficulty that pair skating and singles skating does. Only senior level teams are allowed to do jumps during a specific section of the program, called ‘moves in isolation’. Although there is no limit on what jumps can be performed, synchronized skating teams usually perform single axel jumps, as at least four skaters need to perform the jump cleanly for the element to count and be scored. Despite the discipline of synchronized skating not including many opportunities for skaters to jump, many high-level synchronized skaters are well-rounded skaters, meaning they are proficient in many different divisions of skating, namely freestyle skating and ice dancing. Many synchronized skating teams have their own internal requirements, most of which include freeskate test requirements beyond the USFSA minimum. Because of this, some synchronized skaters have a similar jump history and ability as freestyle skaters. Thus, it is important to include synchronized skaters in figure skating studies.

Previous figure skating jump studies have been conducted to attempt to learn what the forces of high-level jump landings could be doing to the body. Through a study at Brigham Young University, it has been shown that figure skaters absorb up to eight times their own body weight when landing a jump (Hollingshead, 2014). This type of intense training can result in ongoing lower extremity injuries, such as stress fractures and hammertoe. Many conditions that jumpers suffer from are injuries that develop due to overuse, as opposed to an acute event. Injuries that build over time can significantly impair the athletes’ performances physically and mentally. Synchronized skaters, however, may suffer from more acute injuries due to the nature of the sport. Running into other skaters, being dropped from lifts, and being flung off the ends of pinwheels are some examples of how synchronized skaters could suffer from acute injuries.

2.3 Review of Past Literature

There has been very little research done in the realm of ice skating, and even less in the division of figure skating. Studies regarding skating have been almost exclusively done in ice hockey due to exposure and funding by professional leagues throughout the world, as well as access to many participants. Previous research on figure skaters can be divided into three categories: 1) retrospective and cross-sectional injury research in freestyle, pair skaters, and ice
dancers, 2) injury research in synchronized skaters, and 3) analysis of peak ground reaction forces in freestyle skaters.

2.3.1 Freestyle, Pair Skating, and Ice Dancing Injury Research

Injury data is most commonly collected from freestyle and pair skaters because the heavy, repetitive landings of jumps, throws, and lifts raise the most concern in the skating community. Although ice dancing does not have jumps or throws, impact injuries are common during difficult lifts and spins due to the close proximity and high speeds of the dancing partners. The two most common methods of determining the incidence and prevalence of injuries are retrospective injury history, through the use of questionnaires (Dubravcic-Simunjak, Pecina, Kuipera, Moran, & Haspl, 2003; Smith & Ludington, 1989) and cross-sectional medical evaluations (Campanelli, Piscitelli, Verardi, Maillard, & Sbarbati, 2015).

Retrospective Research

The existing injury research heavily involves elite figure skaters, characterized as novice, junior, and senior level skaters. In a study conducted by Dubravcic-Simunjak et al. (2003), the career injury histories of elite Junior World level figure skaters, from all three divisions, were collected through questionnaires, spanning four annual Junior World Championships. The results indicated that 26% of the 469 skaters surveyed suffered from an injury at some point during their career. When combining the results from all three divisions, it was found that both male and female skaters suffered from overuse injuries more often than acute injuries. Stress fractures, jumper’s knee, and shin splits were the most common overuse injuries. This was also true when looking exclusively at the results of freestyle skaters. However, ice dancers and pair skaters suffered from acute injuries more often than overuse injuries, due to the falls and drops from lifts and throws.

Smith and Ludington (1989) conducted a similar questionnaire study involving elite pair skaters and ice dancers. This study looked at injury rates of 48 elite ice dance and pairs teams over a 9-month period, which is roughly a full competitive season. The injuries sustained were classified as “serious” and “less serious,” indicated by days of training missed. The results reported that 24 skaters (25%) sustained “serious” injuries, while 13 skaters (13.5%) sustained “less serious” injuries. There were more injuries reported from the pairs skaters, with nine female and eight male pairs skaters reporting injuries, compared to five female and two male ice
dancers. Senior level skaters reported the most injuries, compared to junior and novice level skaters. Eleven injuries were caused by lifts, while eight injuries were caused by the skating boot. Most of the injuries involved the lower extremities, especially the foot and ankle. The overall findings from this study shed light on the unique risks of partner skating as well as how partner skating effects the injury risk between genders.

Cross-sectional Research

Overuse injuries, especially those of the skin, are rarely given the attention they require, because many skin injuries are not severe enough to prevent training. However, they can compromise the mental aspect of competition, as well as the quality of daily training. In a recent cross-sectional study, 95 skaters were evaluated through a single medical exam (Campanelli, Piscitelli, Verardi, Maillard, & Sbarbati, 2015). This study includes skaters of all levels, and could be useful to younger skaters and non-elite skaters who may not have access to knowledgeable trainers and coaches as elite skaters do.

The results of Campanelli et al. (2015) showed that the two most common overuse skin injuries are retrocalcaneal bursitis and skin calluses of the heel affecting 34% and 29% of the 95 skaters, respectively. In line with the retrospective studies, elite skaters suffered from these conditions anywhere from 10% to 32% more than non-elite skaters. These results were used to identify potential injury risk factors. Risk factors for elite skaters included ill-fitting boots, with only 31.6% of all skaters wearing properly sized boots. Risk factors for non-elite skaters included body weight. Non-elite skaters that had a higher body weight were shown to be at greater risk of retrocalcaneal bursitis. The results from this study are useful to the skating community due to the inclusion of skaters of all levels, and the risk factor analysis that can be used to potentially prevent overuse injuries.

2.3.2 Synchronized Skating Injury Research

Despite the exponential growth of synchronized skating, there are only a few studies that exclusively evaluate the injuries of synchronized skaters. One such retrospective study used a questionnaire to collect the career injury history of 23 teams of skaters during the 2004 World Synchronized Skating Championships (Dubravcic-Simunjak, Kuipers, Moran, Simunjak, & Pecina, 2006). The study investigated the frequency and pattern of injuries, including both acute and overuse injuries.
It was found that 218 of the 514 female skaters (42.4%) and 6 of the 14 male skaters (42.9%) suffered from acute injuries. There were 412 total acute injuries, as some skaters had suffered multiple injuries throughout their career. In both female and male skaters, the most common area of injury was the lower extremities. Overuse injuries were less common, with 69 female skaters and 2 male skaters suffering from lower back problems, and 112 female and 2 male skaters suffering from at least one overuse syndrome over their career. The large number of acute injuries is thought to be because of the contact nature of the sport, with lifts being included in the higher levels. Overuse injuries are not as common as in freestyle because of the exclusion of jumping, which leads to overuse injuries, as seen in Dubravcie-Simujak et al. (2003).

2.3.3 Ground Reaction Force Analysis

Ground reaction forces (GRFs) are the forces exerted by the ground on an object in contact with it. GRFs can be a useful measurement in figure skating because the repetitive, high powered jumps that many skaters perform could lead to overuse injuries, especially those of the lower back and lower extremities. When comparing the vertical ground reaction forces of freestyle skaters with non-skaters, it was found that skaters had a greater normalized peak GRF during landing, a shorter time to peak GRF, and a shorter time to stabilization (Saunders, Hanson, Koutakis, Chaudhari, & Devor, 2014). This gives evidence to the idea that freestyle skaters are putting significantly more force on their bodies than non-skaters, and that this force could directly lead to injury.

When wearing figure skating boots, vertical jump performance changes when compared with barefoot jumping. When comparing barefoot squat jumping, jumping with weights attached to the lower extremities, and jumping in figure skates, it was found that knee and ankle joint amplitude and work output were limited while wearing skates. Jump height and maximal instantaneous power decreased significantly across groups. Additionally, it was found that the maximal vertical ground reaction force was highest and take off time was slowest when wearing skates, however, neither parameter had statistically significant results (Haguenauer, Legreneur, & Monteil, 2006). Ground reaction force analysis between skating divisions would be useful in understanding exactly what is happening to the bodies of different types of skaters when they are training.
Time to stabilization (TTS) has been found to play a role in injury risk not just in figure skaters, but in other sports as well. Athletes in sports such as men’s football, women’s volleyball, and women’s field hockey are at higher risk for anterior cruciate ligament (ACL) injuries, and previous research has found that athletes with ACL tears have shown a slower TTS after ACL reconstruction. A more recent study followed high-risk athletes over a course of four years, and found that athletes who went on to sustain a noncontact ACL rupture demonstrated a slower backward TTS previous to injury than those athletes that did not suffer this injury (DuPrey, Liu, Cronhoim, Reisman, Collina, Webner, & Kaminski, 2016). These results may be applicable to figure skaters, and, by extension, synchronized skaters as the ability to stabilize quickly is important when skating.

2.4 Summary of Current Knowledge

Epidemiology is used when studying injury in defined populations. Prevalence and incidence are two measures commonly used in epidemiology, and the two measures have an important distinction. Risk factors are characteristics that increase the likelihood of sustaining an injury, however causal links cannot be established solely on correlation.

Currently, there is very little research on the sport of figure skating, and even less on the division of synchronized skating. Studies have reported similar results on injury type: freestyle skaters suffer more from overuse injuries, while pair skaters, ice dancers, and synchronized skaters suffer more from acute injuries. This is consistent with the thought that impact injuries have a greater effect on skaters in divisions where more than one skater competes on the ice at the same time.

Both retrospective and cross-sectional studies have reported that higher level skaters suffer from more serious injuries compared to lower level skaters, in both musculoskeletal injuries and skin injuries. Lastly, it has been reported that skaters have a greater peak and normalized GRF, and a shorter TTS compared to non-skaters, and that a longer TTS has been attributed to ACL injury risk in athletes participating in football, volleyball, and field hockey.
3. Methods

3.1 Introduction

This study was conducted during the 2017-2018 synchronized skating season. This was a two-part study, consisting of: 1) questionnaire distribution to skaters of five levels (intermediate, novice, adult, collegiate, and open collegiate), and 2) off-ice jump testing of the open collegiate and collegiate teams.

The questionnaire portion of the study was an epidemiological retrospective study that aimed to compile injury rates and risk factors of synchronized skaters of various competitive levels, skill, age, experience, on-ice practice time and off-ice practice time.

The jumping portion of the study was a cross-sectional study that aimed to compile data on the jumping of two college-level teams. This portion included two comparison groups: skaters that had passed the juvenile freeskate test or above, and those that passed the pre-juvenile freeskate test or below. The juvenile freeskate test was chosen as the cut-off point because this is the first freeskate test where a single axel is required, the highest jump learned before double jumps.

The five levels were specifically chosen because the range in ages, skill level, and experience of the participants differed and thus resulted in clearly defined characteristics that could be assessed for injury risk.

3.2 Participant Recruitment

3.2.1 Intermediate, Novice, and Adult

Female synchronized skaters were recruited from the Eastern and Midwestern sections of the United States. Any skaters active during the 2017-2018 season were eligible to participate. Male skaters were excluded due to lack of sufficient numbers in the division of synchronized skating. Thirty intermediate, novice, and adult skaters (18.47 ± 7.34 years) successfully completed the questionnaires. Five skaters (15.0 ± 0.71 years) were cross-skaters, meaning that they skated on two different leveled teams during one season. Four skaters were intermediate/novice cross-skaters, and one was a novice/junior cross-skater. For the purpose of this study, cross-skaters will be analyzed separately, as they have more on-ice synchronized skating hours than their non-cross-skater counterparts.
3.2.2 Collegiate and Open Collegiate

Female synchronized skaters were recruited from the open collegiate and varsity collegiate teams from Miami University. Any skaters active during the 2017-2018 season were eligible to participate in the questionnaire portion of the study. Skaters were excluded from the jumping portion of the study if they sustained a lower body injury in the past six months that prevented them from jumping. Nine collegiate skaters (20.44 ± 1.13 years) and 14 open collegiate skaters (18.93 ± 1.27 years) successfully completed the questionnaire portion. Two collegiate skaters were excluded from the jumping portion due to existing ankle and knee injuries.

3.3 Instrumentation

3.3.1 Retrospective Questionnaires

Pre-Season Questionnaire

The pre-season questionnaire consisted of two sections: A Skater Profile and an Injury History Profile. The Skater Profile section asked about age, height, weight, years skating per discipline, hours of on-ice and off-ice practice per discipline, skating test history (‘moves in the field’ (MIF), free dance, solo dance, pattern dance, freeskate, and pairs tests), and skate equipment worn.

The Injury History Profile section asked about any injuries that the skater sustained in the 10 years previous to the 2017-2018 synchronized skating season. The season was indicated as beginning at the participants’ respective synchronized skating team’s tryout for the 2017-2018 season.

The Injury History Profile consisted of two parts. The first part asked about injuries that did not require the skater to miss any practice. The second part asks about injuries that did require the skater to miss practice, for any length of time. The questionnaire inquired about the year of injury occurrence, a detailed description of the injury, if the injury was skating related, what skating discipline it was related to, and what, if any, treatment was necessary. The second part of the Injury History Profile also asked about the length of time missed during injury.

Post-Season Questionnaire

The post-season questionnaire consisted only of a Current Injury Profile, and inquired about injuries suffered during the 2017-2018 season. The Current Injury Profile is identical to the
Injury History Profile, except it inquired about the month of injury occurrence, rather than the year. A section at the end of the questionnaire allowed the skater to describe any injuries that are unequalled as of the end of the 2017-2018 season.

3.3.2 Force Plate

To assess the peak vertical landing GRF, flight time, power output, stiffness, and TTS of the participants, an in-ground Bertec 6090-15 force plate (60x90 cm; Bertec Incorporated, Columbus, Ohio) was used. Data was collected at a sampling rate of 1000 Hz, using Vicon Nexus (Oxford Metrics, Oxford, UK) software.

3.4 Data Collection

3.4.1 Intermediate, Novice, and Adult

During the 2017-2018 season, contact was initially made through email with the head coach or director of synchronized skating programs that had at least two of intermediate, novice, or adult level teams active for the 2017-2018 season. The coaches or directors were given information on the questionnaire portion of the study, as well as the given the consent forms and questionnaires that would be given to the skaters. All coaches/directors received the same pre-written information regarding the study. Coaches/directors were encouraged to reach out if they had any hesitations or questions about the study. If the coach/director consented, they then sent out an email to the athletes or parents, if under-18, consisting of the consent/assent forms, pre-season questionnaire, information on the study, and contact information of the researcher. After the 2017-2018 season concluded, the coach/director then sent out the post-season questionnaire. All completed forms were sent directly to the researcher from the athletes or parents.

3.4.2 Open Collegiate

At the beginning of the 2017-2018 season, contact was initially made through email with the head coach of the open collegiate synchronized skating program at Miami University. The coach was given information on the questionnaire and jumping portions of the study, as well as given the consent form and questionnaires that would be completed. The coach was encouraged to reach out if they had any hesitations or questions about the study. The coach then sent out an email to the athletes explaining the study and a link to sign up for times to complete study.
The pre-season questionnaire and jumping portions were completed in one 30-minute session. The participants first filled out a consent form and their height and weight was recorded by the researcher with a Seca stadiometer. The participant then filled out the pre-season questionnaire, and proceeded to the jumping portion.

Participants were asked to stand barefoot in the middle of a Bertec platform and perform a two-foot countermovement jump. The participants were instructed to land in a typical skating landing position: arms extended to their sides, chest up, landing knee slightly bent, with their landing leg extended behind them. The participants were to land their preferred skating landing leg. Three practice trials were completed to diminish any learning effect. Each participant performed three trials of this jump, holding the landing for at least ten seconds. A trial was counted as valid if their free leg did not touch the platform. If the free leg touched the ground or if the participant moved their heel, they were instructed to re-do the trial.

Next, the participants were asked to perform a countermovement jump off each leg individually, landing on their preferred landing foot. They performed three trials on each leg in a blocked design. The starting leg was randomized between participants. Participants followed the same warm-up and trial procedures as the two-foot countermovement jump. The average of three valid trials for each leg were used for analysis. In totality, the participants performed nine practice jumps and nine evaluated countermovement jumps.

Participants then performed drop landings. Participants stood on both feet on a 33 cm high platform. Participants were instructed to drop backward off of the platform and land on their preferred landing leg. Participants were to hold their landing for 10 seconds. A trial was counted as valid if their free leg did not touch the platform and their heel did not move.

Lastly, participants were asked to hop to a metronome set at 132bpm. Participants were to look straight ahead at a black square that was positioned at eye level, keep their hands on their hips, and try to minimize contact time with the force plate. Participants were instructed to hop for at least ten seconds. Participants first hopped off both legs. Two trials were recorded. Participants then alternated between hopping off their left and right legs. This was to limit fatigue after one trial on each leg. The starting leg was randomized and two trials of each leg were recorded.

After the 2017-2018 season concluded, the coach then emailed the post-season questionnaire to all skaters that participated in the pre-season questionnaire and jumping portion.
All completed forms were sent from the athletes directly to the researcher. All skaters completed both the questionnaire and jumping portions.

3.4.3 Collegiate

At the end of the 2017-2018 season, contact was initially made through email with the head coach of the varsity collegiate synchronized skating program at Miami University. The coach was given information on the questionnaire and jumping portions of the study, as well as given the consent form and questionnaires that would be completed. The coach was encouraged to reach out if they had any hesitations or questions about the study. The coach then sent out an email to the athletes explaining the study and a link to sign up for times to complete study.

The pre-season questionnaire, post-season questionnaire and jumping portions were completed in one 30-minute session. The participants first filled out a consent form and their height and weight was measured by the researcher with a Seca stadiometer. The participants then filled out the pre-season and post-season questionnaires, and then proceeded to the jumping portion. The collegiate athletes completed a jumping protocol identical to the protocol completed by the open collegiate athletes. Two athletes did not complete the jumping portion due to injury.

3.5 Statistical Analysis

3.5.1 Questionnaires

After receiving all completed questionnaires, the data was quantified and fed into a computer using Microsoft Excel software (v.16.11.1) and quantified for analysis. Statistical analyses was performed with SPSS software (v.25.0; IBM Corp., 2017). One-way analysis of variance (ANOVA) and Kruskal-Wallis ANOVA tests were used for group comparisons.
Injury prevalence and synchronized skating injury incidence were calculated through the following equations:

**Prevalence:**
Percent (%) of population = \( \frac{\text{(# of injuries reported)}}{\text{( # of participants in population)}} \) * 100

**Incidence:**
Injuries per 1000 practice hours = \( \frac{\text{# of injuries}}{\left( \text{average synchro practice time} \times 36 \text{ weeks} \times \text{# of athletes in population} \right)} \) * 1000

3.5.2 Jumping Analysis
Total percent of time spent off the force plate was taken from the hopping trials. This was calculated by taking the smallest amount of time spent off the force plate during hopping and normalized for each subject when they left the force plate, and were in the air. The amount of time off the force plate was counted until just past 10 seconds for each subject. The total time off the force plate was then divided by the normalized trial time to account for percent of time spent off the force plate. This was calculated for hopping on both legs (BLH), hopping on left leg (LLH), and hopping on right leg (RLH) and recorded in percent (%). This variable was used as a way to quantify stiffness of the participants between groups.

Flight time was taken from the countermovement jumping trials. Flight time was recorded from the force plate as the time off the force plate (0 reading to 0 reading) during the jump. The trial with the longest flight time was used for analysis. Flight time was recorded for jumping off both legs (BLJ), jumping off the left leg (LLJ), and jumping of the right leg (RLJ) in seconds (s).

The peak force generated from the vertical countermovement jump was recorded from the force plate. The trial with the greatest peak force was used for analysis. Peak force was recorded for jumping off both legs (BLJpeak), jumping off the left leg (LLJpeak), and jumping off the right leg (RLJpeak) in newtons (N).

TTS was calculated from the box drop trials, which required the participants to land and remain stable. A ‘stable position’ was defined as when the participant remained within 1 body weight (±5% of body weight) for 0.5 seconds after landing. This time started when the participant was within body weight and was maintained for another 499 measures. If this did not
occur, the next time they were within body weight was when counting began, until they were within 1 body weight for 0.5 seconds. The time recorded for the purpose of this study is derived from the start time of the 0.5 seconds minus the moment of landing on the force plate, and does not include the extra 0.5 seconds required to be counted as stable. TTS was recorded in seconds (s).

The power output from the vertical countermovement jump was recorded from the force plate. The trial with the greatest peak force was used for analysis. Peak force was recorded for jumping off both legs (BLJpo), jumping off the left leg (LLJpo), and jumping off the right leg (RLJpo) in watts (W).

An unequal variance t-test (Welch t-test) was used to compare flight time, TTS, peak force, power output, and percent time off the force plate between two unbalanced groups.
4. Results

4.1 Athlete Demographics

4.1.1 Overview

A total of 58 synchronized skaters were included in this study. There was no difference in average height between skating levels. The collegiate team skaters were significantly heavier (p<.05) and older than the novice, intermediate, and cross-skaters. Cross-skaters and collegiate skaters had significantly more (p<.05) total on-ice practice time and synchro practice time, as cross-skaters participated in two team’s worth of practices and collegiate skated everyday as a varsity team. The adult team was on average significantly older (p<.05) than all the other teams except the collegiate team, however the adult team was still on average about 10 years older than the collegiate team, with the oldest participating adult level skater being 41 years old. The adult team also had significantly less synchronized skating practice hours than every other team except the open collegiate team. The full breakdown of descriptive characteristics by team can be seen in Table 3.

<table>
<thead>
<tr>
<th></th>
<th>Intermediate n=12</th>
<th>Novice n=11</th>
<th>Adult n=7</th>
<th>Open Collegiate n=14</th>
<th>Collegiate n=9</th>
<th>Cross-skaters n=5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>15.25 (1.60)</td>
<td>14.64 (1.57)</td>
<td>30.00 (6.98)</td>
<td>18.93 (1.27)</td>
<td>20.44 (1.13)</td>
<td>15.0 (0.71)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.61 (0.13)</td>
<td>1.60 (1.57)</td>
<td>1.61 (0.07)</td>
<td>1.65 (0.05)</td>
<td>1.67 (0.076)</td>
<td>1.60 (0.27)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>55.36 (11.65)</td>
<td>54.30 (12.08)</td>
<td>60.19 (8.85)</td>
<td>65.39 (10.99)</td>
<td>68.97 (6.24)</td>
<td>55.16 (4.49)</td>
</tr>
<tr>
<td>Years Skating Total</td>
<td>9.75 (2.56)</td>
<td>8.91 (2.85)</td>
<td>23.14 (5.63)</td>
<td>13.64 (1.45)</td>
<td>14.67 (3.71)</td>
<td>7.30 (0.84)</td>
</tr>
<tr>
<td>Years Skating Synchro</td>
<td>6.83 (2.48)</td>
<td>6.45 (1.37)</td>
<td>18.57 (6.92)</td>
<td>7.36 (5.18)</td>
<td>10.55 (4.0)</td>
<td>6.20 (1.30)</td>
</tr>
<tr>
<td>Total on-ice practice per week (hr)</td>
<td>7.75 (2.79)</td>
<td>8.0 (2.53)</td>
<td>2.61 (0.96)</td>
<td>4.61 (2.07)</td>
<td>7.83 (3.89)</td>
<td>13.20 (3.09)</td>
</tr>
<tr>
<td>Synchro on-ice practice per week (hr)</td>
<td>3.67 (0.78)</td>
<td>4.36 (1.10)</td>
<td>1.68 (0.77)</td>
<td>2.43 (0.50)</td>
<td>7.28 (2.02)</td>
<td>9.13 (1.12)</td>
</tr>
<tr>
<td>Total off-ice practice per week (hr)</td>
<td>3.79 (1.62)</td>
<td>3.07 (1.49)</td>
<td>1.36 (1.03)</td>
<td>3.14 (2.29)</td>
<td>3.61 (1.54)</td>
<td>4.132 (2.22)</td>
</tr>
<tr>
<td>Synchro off-ice practice per week (hr)</td>
<td>1.92 (1.51)</td>
<td>2.18 (1.18)</td>
<td>1.00 (0.96)</td>
<td>1.86 (0.75)</td>
<td>4.11 (1.56)</td>
<td>3.55 (2.56)</td>
</tr>
</tbody>
</table>

Note: Values are expressed as mean (SD)
4.2 Injury Prevalence and Classification

4.2.1 Overview

Of the 58 participating skaters, 44 (75.9%) reported 92 total skating related injuries with 69 (78.4%) of the injuries occurring in the 10 years prior to the 2017-2018 season. Of the 92 total injuries, 51 (55.4%) were related to synchronized skating. There were 67 (72.8%) total acute injuries and 25 (27.2%) total overuse injuries reported. Of the 51 synchronized skating injuries, 35 (68.6%) were acute injuries and 16 (31.3%) were overuse injuries. The respondents reported 28 head/spine, 5 hip, 15 wrist/finger/hand, 9 leg, 14 knee, and 21 foot/ankle injuries. The full break down of the total injuries can be seen in Table 4. There were 11 total concussions reported.

<table>
<thead>
<tr>
<th></th>
<th>Occurred During Figure Skating</th>
<th>Occurred During Synchronized Skating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acute(%)</td>
<td>Overuse(%)</td>
</tr>
<tr>
<td>Head/spine</td>
<td>25 (89%)</td>
<td>3 (11%)</td>
</tr>
<tr>
<td>Hip</td>
<td>2 (40%)</td>
<td>3 (60%)</td>
</tr>
<tr>
<td>Arm</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wrist/hand/fingers</td>
<td>14 (93%)</td>
<td>1 (7%)</td>
</tr>
<tr>
<td>Leg</td>
<td>6 (67%)</td>
<td>3 (33%)</td>
</tr>
<tr>
<td>Knee</td>
<td>9 (64%)</td>
<td>5 (36%)</td>
</tr>
<tr>
<td>Foot/ankle</td>
<td>11 (52%)</td>
<td>10 (48%)</td>
</tr>
</tbody>
</table>

a Refers to all disciplines of skating including synchronized skating

There were 55 (59.8%) total injuries and 28 (54.9%) synchronized skating injuries that required practice time missed. The burden of injury was classified by injury region and the full breakdown can be seen in Figure 2.
Figure 2 Average Practice Time Missed due to Synchronized Skating Injury by Region of Injury in All Participants (n=58)

4.2.1 Intermediate

Twelve intermediate skaters participated. Of the 12 participants, 2 reported passing their senior MIF, 2 reported junior, 3 reported novice, 4 reported intermediate, and 1 reported juvenile. Two skaters reported passing the preliminary pattern dance test, 1 pre-bronze, 1 bronze, 1 pre-gold, and 1 gold. Three skaters passed the pre-preliminary freeskate test, one preliminary, 2 pre-juvenile, 1 juvenile, and 1 junior. One skater passed the silver free dance. Of the 12 participants, 8 reported wearing Jackson boots, 2 Riedell, 1 Edea, and 1 SP-Teri. Blades worn were split between Jackson (1 Elle, 1 Elite, 1 Finesse, and 1 unreported) and John Wilson (2 Patter 99, 2 Coronation Ace, 1 Gold Seal, 1 Parabolic). Two skaters did not report their blade type. When skating, 2 skaters reported wearing bunga pads, 2 arch supports, 1 gel pads, and 1 custom insoles.
Table 5 Absolute and Relative (%) Numbers of Acute and Overuse Injuries in Female Intermediate Synchronized Skaters (n=12)

<table>
<thead>
<tr>
<th></th>
<th>Occurred During Figure Skatinga</th>
<th>Occurred During Synchronized Skating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acute(%) Overuse(%)</td>
<td>Acute(%) Overuse(%)</td>
</tr>
<tr>
<td>Head/spine</td>
<td>2 (67%) 1 (33%)</td>
<td>0 1 (100%)</td>
</tr>
<tr>
<td>Hip</td>
<td>0 0</td>
<td>0 0</td>
</tr>
<tr>
<td>Arm</td>
<td>0 0</td>
<td>0 0</td>
</tr>
<tr>
<td>Wrist/hand/fingers</td>
<td>8 (100%) 0</td>
<td>4 (100%) 0</td>
</tr>
<tr>
<td>Leg</td>
<td>0 1 (100%)</td>
<td>0 1 (100%)</td>
</tr>
<tr>
<td>Knee</td>
<td>0 0</td>
<td>0 0</td>
</tr>
<tr>
<td>Foot/ankle</td>
<td>2 (33%) 4 (67%)</td>
<td>1 (25%) 3 (75%)</td>
</tr>
</tbody>
</table>

a Refers to all disciplines of skating including synchronized skating

Among the 12 intermediate skaters, 10 (83.3%) reported 18 total skating injuries, with 12 (66.7%) injuries occurring before the 2017-2018 season. Four (40%) of the injury-reporting skaters suffered more than one injury. Of the 18 injuries, 11 (61.1%) were related specifically to synchronized skating, with 6 (54.5%) occurring before the 2017-2018 season and 5 (45.5%) occurring during the season. There were 12 (66.7%) total acute injuries and 6 (33.3%) total overuse injuries reported. Of the 11 synchronized skating injuries, 5 were acute (45.5%) and 6 (54.5%) overuse, with 2 (40%) of the acute and 4 (66.7%) of the overuse injuries sustained prior to the 2017-2018 season. The full break down of the injuries can be seen in Table 5. Overall, there were 6.9 synchro injuries per 1000 synchro practice hours reported for the 2017-2018 season.

The respondents reported 8 wrist/hand/finger, 6 foot/ankle, 3 head/spine, and 1 leg injury. Injuries included sprained, fractured, and broken wrists, plantar fasciitis, an inflamed Achilles tendon, a foot stress fracture, a tailbone bruise, a deep cut on hand requiring stitches, a sprained ankle, shin splints, overuse back injuries, and a concussion. The ankle sprain was unhealed as of the end of the 2017-2018 season.
There were 9 (50%) total injuries and 4 (36.4%) synchronized skating injuries that required time missed. The average time needed off the ice due to injury was 3.3 weeks for all skating injuries and 4.25 weeks for synchronized skating injuries. The burden of injury was classified by injury region. Foot injuries required 9 weeks missed, while wrist, leg, ankle injuries required 6 weeks, 1 week, and 1 week missed, respectively. The full synchronized skating burden breakdown is pictured in Figure 3. Although they were not synchronized skating related injuries, 2 freestyle wrist injuries, 2 ankle injuries, and 1 head injury cost 8 weeks, 4 weeks, and 1 week of missed practice, respectively. One massive non-skating related head injury was reported that cost 8 months off the ice, with over a year of post-concussive symptoms and subsequent therapy reported.

4.2.2 Novice

Eleven novice skaters participated. Four skaters reported passing the intermediate MIF test, 3 reported novice, 2 reported junior, and 2 reported senior. Two skaters passed the pre-
bronze dance tests, 2 reported bronze, 4 pre-silver, 1 silver, and two did not reported passing a dance test. One skater reported passing the pre-silver free dance test. Five skaters reported passing the pre-preliminary freeskate test, 1 the preliminary, 1 pre-juvenile, 1 juvenile, 1 intermediate, and 1 novice. One skater did not report passing a freeskate test. Of the 11 skaters, 4 reported wearing Jackson boots, 4 Edea (3 Chorus, 1 Flamenco), 2 Riedell, and 1 Risport. Four skaters reported wearing John Wilson blades (3 Pattern 99, 1 Coronation Ace), 4 MK blades, 2 Jackson Matrix, and 1 Riedell Quest. When skating, 5 skaters reported wearing gel pads or sleeves and 3 reported wearing custom insoles.

Table 6 Absolute and Relative (%) Numbers of Acute and Overuse Injuries in Female Novice Synchronized Skaters (n=11)

<table>
<thead>
<tr>
<th></th>
<th>Occurred During Figure Skating(^a)</th>
<th>Occurred During Synchronized Skating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acute(%)</td>
<td>Overuse(%)</td>
</tr>
<tr>
<td>Head/spine</td>
<td>3 (60%)</td>
<td>2 (40%)</td>
</tr>
<tr>
<td>Hip</td>
<td>1 (100%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Arm</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wrist/hand/fingers</td>
<td>2 (67%)</td>
<td>1 (33%)</td>
</tr>
<tr>
<td>Leg</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Knee</td>
<td>2 (67%)</td>
<td>1 (33%)</td>
</tr>
<tr>
<td>Foot/ankle</td>
<td>2 (50%)</td>
<td>2 (50%)</td>
</tr>
</tbody>
</table>

\(^a\) Refers to all disciplines of skating including synchronized skating

Among 11 novice skaters, 8 (72.7%) skaters reported 16 total injuries, with 11 (68.8%) occurring before the 2017-2018 season. Of the 8 injury-reporting skaters, 4 (50%) sustained more than one injury. Of the 16 total injuries, 12 (75%) were related to synchronized skating, with 7 (58.3%) occurring before the 2017-2018 season and 5 (41.7%) occurring during the season. There were 10 (62.5%) total acute and 6 (37.5%) total overuse injuries. Of the 12 synchronized skating injuries, 8 (66.7%) were acute injuries, and 4 (33.3%) were overuse injuries, with 5 (41.7%) of the acute and 2 (16.7%) of the overuse injuries sustained prior to the 2017-2018 season. The full breakdown of injuries can be seen in Table 6. Overall, there were 6.9 synchro injuries per 1000 synchro practice hours reported for the 2017-2018 season.
The respondents reported 5 head/spine, 4 foot/ankle, 2 wrist/finger/hand, 3 knee, and 1 hip injury. There were no arm or leg injuries reported. Injuries included contusions, a broken wrist, scapular dyskinesia, a sprained ankle and wrist, a bruised tailbone, a costochondral and osteochondral lesion, bilateral spondylolysis, hip contusions, and two re-aggravations of past injuries. One skater suffered from a re-aggravated spondylolysis that lead to a back fracture and eventual spinal fusion surgery. Another skater suffered from an osteochondral lesion in her ankle, which is a chronic condition, and was thus unhealed as of the end of the season. One skater reported a non-skating related concussion prior to the season.

**Figure 4** Average Practice Time Missed due to Synchronized Skating Injury by Region of Injury in Novice Skaters (n=11)

There were 7 (43.8%) total injuries and 5 (31.3%) synchronized skating injuries that required time missed. The average time missed due to injury was 15 weeks for all skating related injuries, and 7 weeks for synchronized skating specific injuries. The burden of injury was classified by injury region. Back and ankle injuries required the most time missed, at an average of 24 weeks each. Hip injuries and hand/wrist injuries also resulted in missed practice time. The
full synchronized skating injury burden breakdown is pictured in Figure 4. Although they were not synchronized skating related injuries, a concussion and a costochondral lesion were sustained during freestyle skating, costing 4 and 24 weeks, respectively.

4.2.3 Cross-skaters

Five cross-skaters (4 intermediate/novice and 1 novice/junior) participated. All 4 intermediate/novice cross-skaters reported passing their intermediate MIF and bronze dance tests, while 3 passed their pre-preliminary freeskate test and 1 had not passed a freeskate test. One intermediate/novice skater reported passing the first figures test. The novice/junior cross-skater reported passing her junior MIF, bronze dance test, and pre-juvenile freeskate test.

Three skaters wore Jackson boots and 2 wore Edeas. Two skaters wore John Wilson blades (1 Pattern 99, 1 Coronation Ace) and 2 wore MK Professional. One participant did not report her blade type. All 5 skaters reported wearing gel pads. One wore foam circles and 1 wore insoles with the gel pads.

<table>
<thead>
<tr>
<th>Table 7 Absolute and Relative (%) Numbers of Acute and Overuse Injuries in Female Cross-level Synchronized Skaters (n=5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occurred During Figure Skating(^a)</td>
</tr>
<tr>
<td>Acute(%)</td>
</tr>
<tr>
<td>Head/spine</td>
</tr>
<tr>
<td>Hip</td>
</tr>
<tr>
<td>Arm</td>
</tr>
<tr>
<td>Wrist/hand/fingers</td>
</tr>
<tr>
<td>Leg</td>
</tr>
<tr>
<td>Knee</td>
</tr>
<tr>
<td>Foot/ankle</td>
</tr>
</tbody>
</table>

\(^a\) Refers to all disciplines of skating including synchronized skating; \(^b\) overuse foot injury noted as being exacerbated by synchro skating

Among 5 cross-skaters, 3 (60%) skaters reported 3 total skating injuries, with all injuries occurring before the 2017-2018 season. There was 1 (33%) total acute injury and 2 (67%) total
overuse injuries. No injuries were related specifically to synchronized skating, however 1 (33%) injury was reported as exacerbated by synchronized skating practice. The full breakdown of injuries can be seen in Table 7.

The respondents reported 1 leg injury and 2 foot/ankle injuries. Reported injuries included a broken ankle, pulled hamstring, and overuse complications from a pronated foot. There were 2 (67%) injuries that required time missed. The average time needed off the ice due to injury was 6.0 weeks for all skating related injuries. Since there were no synchronized skating injuries, there was no time lost due to synchro injuries, however the pronated foot injury was exacerbated by synchronized skating and the injury complications extended through the end of the 2017-2018 season. The burden of injury was classified by injury region. The broken ankle and pronated foot injuries both required 6 weeks off the ice prior to the 2017-2018 season.

4.2.4 Adult

Seven adult skaters participated. Three skaters reported passing the senior MIF test, 1 reported junior, 2 novice, and 1 intermediate. One skater passed the preliminary pattern dance test, 1 bronze, 2 pre-silver, and 2 silver. One skater passed the juvenile free dance test. One skater passed the senior freeskate test, 1 reported novice, 3 juvenile, 1 pre-juvenile, and 1 pre-preliminary. Of the 7 skaters, 2 skaters reported wearing Riedell boots, 3 Jackson, 1 Edea, and 1 SP-Teri. Blades were split between MK (1 Professional, 1 Synchro), Jackson (2 Ultima, 1 Synchro) and John Wilson (1 Coronation Ace, 1 Pattern 99). One skater reported wearing bunga pads while skating, and one reported wearing custom orthotic insoles.

Of the 7 adult skaters, 3 (42.9%) skaters reported 4 total injuries. All 3 injuries occurred before the 2017-2018 season. Three injuries were specifically related to synchronized skating. The non-synchro related injury was vertigo from spinning which required an inner ear balance, and cost 2 weeks of missed practice. One synchronized skating injury was an acute laceration to the left calf due to falling backwards into another skater during synchro practice, and did not require any time missed. The other two injuries were a knee contusion and hip overuse injuries, each of which required 2 weeks of missed practice.
Table 8 Absolute and Relative (%) Numbers of Acute and Overuse Injuries in Female Adult Synchronized Skaters (n=7)

<table>
<thead>
<tr>
<th></th>
<th>Occurred During Figure Skating(^a)</th>
<th>Occurred During Synchronized Skating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acute(%)</td>
<td>Overuse(%)</td>
</tr>
<tr>
<td>Head/spine</td>
<td>1 (100%)</td>
<td>0</td>
</tr>
<tr>
<td>Hip</td>
<td>0</td>
<td>1 (100%)</td>
</tr>
<tr>
<td>Arm</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wrist/hand/fingers</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Leg</td>
<td>1 (100%)</td>
<td>0</td>
</tr>
<tr>
<td>Knee</td>
<td>1 (100%)</td>
<td>0</td>
</tr>
<tr>
<td>Foot/ankle</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

\(^a\) Refers to all disciplines of skating including synchronized skating

4.2.5 Open Collegiate

Fourteen open collegiate skaters participated. Five skaters reported passing the senior MIF test, while 4 passed junior, 2 novice, 1 intermediate, 1 juvenile, and 1 pre-juvenile. Five skaters reported passing pattern dance tests, with 3 passing pre-gold, 1 passing pre-silver, and 1 passing bronze. One skater reported passing the senior free dance test. Two skaters reported passing solo free dance tests, with 1 passing senior and 1 silver. Of the 14 skaters, 1 passed the novice freeskate test, 2 intermediate, 5 juvenile, 4 pre-juvenile, and 2 did not report passing any freeskate tests. Four skaters reported wearing Jackson boots, while 4 wore Riedell, 3 Edea, 1 GAM, 1 SP-Teri, and 1 Harlick. Blades were split between Jackson (3 Ultima, 1 Elite, 1 Eclipse), John Wilson (3 Pattern 99, 1 Coronation Ace), MK (2 Vision, 1 K-pick), and 1 Paramount. One skater did not report their blade type. When skating, 4 skaters reported wearing bunga pads, 3 wore gel pads, and 1 wore custom arch supports.
Table 9 Absolute and Relative (%) Numbers of Acute and Overuse Injuries in Female Open Collegiate Synchronized Skaters (n=14)

<table>
<thead>
<tr>
<th></th>
<th>Occurred During Figure Skating</th>
<th>Occurred During Synchronized Skating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acute(%)</td>
<td>Overuse(%)</td>
</tr>
<tr>
<td>Head/spine</td>
<td>14 (100%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Hip</td>
<td>0 (0%)</td>
<td>1 (100%)</td>
</tr>
<tr>
<td>Arm</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wrist/hand/fingers</td>
<td>3 (100%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Leg</td>
<td>1 (50%)</td>
<td>1 (50%)</td>
</tr>
<tr>
<td>Knee</td>
<td>3 (75%)</td>
<td>1 (25%)</td>
</tr>
<tr>
<td>Foot/ankle</td>
<td>4 (100%)</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>

Among the 14 open collegiate skaters, 12 (85.7%) skaters reported 28 total injuries, with 26 (92.9%) of injuries occurring before the 2017-2018 season. Five (41.6%) of the injury-reporting skaters suffered more than one injury. Of the 28 injuries, 10 (35.7%) of were related to synchronized skating, with 8 (80%) occurring before the 2017-2018 season and 2 (20%) occurring during the season. There were 25 (89.2%) total acute injuries and 3 (10.7%) total overuse injuries. Of the 10 synchronized skating injuries, 9 (90%) were acute injuries and 1 (10%) was an overuse injury, with 7 (77.78%) of the acute and the 1 overuse injury occurring prior to the 2017-2018 season. The full break down of injuries can be seen in Table 9. Overall, there were 8.2 synchro injuries per 1000 synchro practice hours reported for the 2017-2018 season.

The respondents reported 14 head/spine, 4 foot/ankle, 4 knee, 3 wrist/hand/fingers, 2 leg, and 1 hip injuries. No arm injuries were reported. Reported injuries included 8 concussions, an ankle fracture, 2 wrist fractures, a black eye, a cut lip, ankle sprains, whiplash, knee stress fractures and muscle pulls, hip bursitis, an Achilles sprain, a meniscus tear, and a cut finger requiring stitches. Although there were 8 concussions, 1 person sustained 5 of them, while another person sustained the other 3. The worst concussion required cocoon therapy.
There were 22 (78.6%) total injuries and 7 (70%) synchronized skating injuries that required time missed. The average time needed off the ice due to injuries was reported as 5.07 weeks for all skating injuries, and 4.0 weeks for synchronized skating injuries. The burden of injury was classified by injury region. Leg injuries required the most time away at 8 weeks reported before the 2017-2018 season and 1 week missed during the season. However, due to the number of head and back injuries reported, the average time missed was lower than the worst head injury’s impact. The worst concussion required over a year of recovery, while many of the smaller reported concussions only required a short amount of time off the ice. Neck injuries were classified separately from head and back injuries due to the differing nature of the injuries. The whiplash neck injury required 4 weeks missed and was sustained by falling backwards on a teammate during synchro practice. The full synchronized skating injury burden breakdown is pictured in Figure 5. Non-synchronized skating knee, ankle, and hip injuries also resulted in missed practice time. Two non-skating related concussions were reported.
4.2.6 Collegiate

Nine collegiate skaters participated. All 9 collegiate skaters reported passing their senior MIF test, and 7 reported passing the silver pattern dance test or above. Seven skaters passed the juvenile freeskate test or above. One skater passed the senior free dance test.

Of the 9 skaters, 4 skaters reported wearing Jackson boots, 3 Riedell, 1 SP-Teri, and 1 Edea. Blades worn were split between Jackson (3 Ultima, 1 Synchro), Riedell (3 Eclipse, 1 Dance), and John Wilson (1 Goal Seal). When skating, 2 skaters reported wearing bunga pads, 2 pre-wrap, and 1 foam circles.

Table 10 Absolute and Relative (%) Numbers of Acute and Overuse Injuries in Female Collegiate Synchronized Skaters (n= 9)

<table>
<thead>
<tr>
<th></th>
<th>Occurred During Figure Skatinga</th>
<th>Occurred During Synchronized Skating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acute(%) Overuse(%)</td>
<td>Acute(%) Overuse(%)</td>
</tr>
<tr>
<td>Head/spine</td>
<td>4 (100%) 0 (0%)</td>
<td>4 (75%) 0 (25%)</td>
</tr>
<tr>
<td>Hip</td>
<td>1 (100%) 0 (0%)</td>
<td>1 (100%) 0 (0%)</td>
</tr>
<tr>
<td>Arm</td>
<td>0 0</td>
<td>0 0</td>
</tr>
<tr>
<td>Wrist/hand/fingers</td>
<td>1 (100%) 0 (0%)</td>
<td>1 (100%) 0 (0%)</td>
</tr>
<tr>
<td>Leg</td>
<td>3 (100%) 0 (0%)</td>
<td>2 (100%) 0 (0%)</td>
</tr>
<tr>
<td>Knee</td>
<td>3 (60%) 2 (40%)</td>
<td>2 (50%) 2 (50%)</td>
</tr>
<tr>
<td>Foot/ankle</td>
<td>2 (40%) 3 (60%)</td>
<td>2 (67%) 1 (33%)</td>
</tr>
</tbody>
</table>

a Refers to all disciplines of skating including synchronized skating

Among 9 collegiate skaters, 8 (88.9%) skaters reported 19 total skating injuries, with 14 (73.7%) injuries occurring before the 2017-2018 season. All 8 (100%) of the injury-reporting skaters suffered more than one injury. Of the 19 injuries, 15 (78.9%) were related specifically to synchronized skating, with 10 (67%) occurring before the 2017-2018 season and 5 (33%) during the season. There were 14 (73.3%) total acute injuries and 5 (26.3%) total overuse injuries reported. Of the 15 synchronized skating injuries, 12 (80.0%) acute and 3 (20.0%) overuse injuries were reported, with 9 (75.0%) of the acute and 1 (33.3%) of the overuse injuries sustained prior to the 2017-2018 season. The full break down of injuries can be seen in Table 10. Overall, there were 6.4 synchro injuries per 1000 synchro practice hours reported for the 2017-2018 season.
The respondents reported 5 knee, 5 foot/ankle, 4 head/spine, 3 leg, 1 wrist/hand/finger, 3 leg, 1 hip, and no arm injuries. Injuries included tendinitis, bursitis, a groin pull, sprains of the ankle, wrist, and gastrocnemius, a lower leg spiral fracture, a herniated lumbar disk, a torn meniscus, a sprained MCL and full ACL tear, a pinkie toe break, and 2 concussions. One skater suffered from an ankle sprain and ankle tendonitis that was unhealed as of the end of the 2017-2018 season.

**Figure 6** Average Practice Time Missed due to Synchronized Skating Injury by Region of Injury in Collegiate-level Skaters (n= 9)

![Practice Time Missed (weeks) vs Region of Injury](image)

There were 12 (63.2%) total injuries and 10 (66.7%) synchronized skating injuries that required time missed. The average time needed off the ice due to injury was reported as 8.71 weeks for all skating related injuries. Synchronized skating specific related injuries required an average of 6.13 weeks off the ice. The burden of injury was classified by injury region. Knee injuries required the most practice time missed, at an average of 24 weeks reported for the injuries that occurred before the 2017-2018 season, and 3 weeks for the injuries reported during the season. The foot/ankle and head/spine region injuries also resulted in missed practice time.
Two synchronized skating related concussions resulted in an average of 8 weeks of missed practice. The full synchronized skating injury burden breakdown is pictured in Figure 6. Although they were not synchronized skating related injuries, a freestyle skating leg fracture and kneecap injury were reported that cost 14 weeks and 8 weeks of missed practice, respectively.

4.3 Injury Risk Factors

Age, team level, practice time per week, boot brand, years skating, and test level were grouped and compared to injury prevalence.

4.3.1 Age

Age of participants were split into 5 group ranges: 12-15, 16-19, 20-23, 24-27, 28 and above. Total injuries and synchro injuries were compared across age groups. There were no significant differences between total injury across age groups (p=0.151) or synchro injury across age groups (p=0.203).

4.3.2 Team Level

Total injuries and synchro injuries were compared across team level (intermediate, novice, cross, adult, collegiate, open collegiate). There were no significant differences between total injury across team level (p=0.272) or synchro injury across team level (p=0.527).

4.3.3 Boot Brand

Total injuries and synchro injuries were compared across boot brand (Jackson, Edea, Riedell, and ‘other’). ‘Other’ included 3 other brands of boot (4 SP-Teri, 1 Risport, 1 Harlick, and 1 GAM). There were no significant differences between total injury across boot brand (p=0.418) or synchro injury across boot brand (p=0.089).

4.3.4 Test Level

Total injuries and synchro injuries were compared across MIF and freeskate test level. Test levels were split into 3 groups: 1) pre-preliminary through pre-juvenile, 2) juvenile through intermediate, 3) novice through senior. There were no significant differences between injury across freeskate test level (total: p=0.353, synchro: p=0.435), or total injury across MIF
(p=0.079). A significant difference was found between synchro injury and MIF test level (p=0.017). A pairwise comparison revealed a significant difference between juvenile through intermediate and novice through senior. The full comparison can be seen in Table 11.

**Table 11** Pairwise Comparisons of Synchronized Skating Injuries across MIF Test Level

<table>
<thead>
<tr>
<th></th>
<th>Test Statistic</th>
<th>Std. Error</th>
<th>Std. Test Statistic</th>
<th>Significance</th>
<th>Adj. Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1-Group 2</td>
<td>-3.125</td>
<td>15.200</td>
<td>-0.206</td>
<td>0.837</td>
<td>1.000</td>
</tr>
<tr>
<td>Group 1-Group 3</td>
<td>-15.049</td>
<td>14.925</td>
<td>-1.008</td>
<td>0.313</td>
<td>0.940</td>
</tr>
<tr>
<td>Group 2-Group 3</td>
<td>-11.924</td>
<td>4.347</td>
<td>-2.743</td>
<td>0.006</td>
<td>0.018 *</td>
</tr>
</tbody>
</table>

* p<0.05

4.3.5 Years Skating Synchro

Years spent synchronized skating was split into 5 groups: 1-5 years, 6-10, 11-15, 16-20, 21 and above. Total number of synchronized skating injuries were compared across these groups. No significant differences in synchro injuries and years spent skating synchro were found (p=0.599).

4.3.6 Synchro Practice Time per week

Synchronized skating practice time per week was split into 6 groups: 0-2.5 hours, 3-5.5, 6-8.5, 9-11.5, 12-14.5, 15 and above. Total number of synchronized skating injuries were compared across these groups. No significant differences in synchro injuries and synchro practice time per week were found (p=0.241).

4.3.7 Concussions

Total concussions reported were compared across boot brand (Jackson, Edea, Riedell, and ‘other’). ‘Other’ included 3 other brands of boot (4 SP-Teri, 1 Risport, 1 Harlick, and 1 GAM). A significant difference (p=0.037) was found. A pairwise comparison revealed a
significant difference between Edea and Jackson boots. The full comparison can be seen in Table 12.

Table 12 Pairwise Comparisons of Concussions Across Boot Brand

<table>
<thead>
<tr>
<th></th>
<th>Test Statistic</th>
<th>Std. Error</th>
<th>Std. Test Statistic</th>
<th>Significance</th>
<th>Adj. Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jackson-Other</td>
<td>1.077</td>
<td>3.799</td>
<td>0.283</td>
<td>0.777</td>
<td>1.000</td>
</tr>
<tr>
<td>Riedell-Other</td>
<td>2.423</td>
<td>4.182</td>
<td>0.579</td>
<td>0.562</td>
<td>1.000</td>
</tr>
<tr>
<td>Edea-Other</td>
<td>9.542</td>
<td>4.243</td>
<td>2.249</td>
<td>0.025</td>
<td>0.147</td>
</tr>
<tr>
<td>Jackson-Riedell</td>
<td>-1.346</td>
<td>3.030</td>
<td>-0.444</td>
<td>0.657</td>
<td>1.000</td>
</tr>
<tr>
<td>Jackson-Edea</td>
<td>-8.465</td>
<td>3.113</td>
<td>-2.719</td>
<td>0.007</td>
<td>0.039 *</td>
</tr>
<tr>
<td>Riedell-Edea</td>
<td>7.119</td>
<td>3.571</td>
<td>1.993</td>
<td>0.046</td>
<td>0.277</td>
</tr>
</tbody>
</table>

* p<0.05

No differences in number of concussions sustained were found across age (p=0.583), team (p=0.620), synchro practice time per week (p=0.748), or years skating synchro (p=0.748).

4.4 Off-ice Jump Landing Variables

4.4.1 Athlete Demographics

Seven collegiate and 14 open collegiate skaters completed the jumping portion. Five participants were excluded from the analysis due to data collection error. After completing the jumping portion, the data from the 6 open collegiate and 10 collegiate skaters were divided into 2 groups. The Low Freeskate Group was comprised of skaters who have passed the pre-juvenile freeskate test or lower, and the High Freeskate Group was comprised of skaters who have passed the juvenile freeskate test or above. The breakdown of characteristics by group can be seen in Table 13.
Table 13 Descriptive Characteristics for Jumping Participants (n=16)

<table>
<thead>
<tr>
<th></th>
<th>Low Freeskate Group (n=6)</th>
<th>High Freeskate Group (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>18.33 (0.82)</td>
<td>19.70 (1.16)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.67 (0.07)</td>
<td>1.65 (0.07)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>71.83 (9.84)</td>
<td>64.26 (10.08)</td>
</tr>
<tr>
<td>Years Skating Total</td>
<td>13.17 (2.32)</td>
<td>14.20 (2.04)</td>
</tr>
<tr>
<td>Year Skating Synchro</td>
<td>5.50 (5.13)</td>
<td>9.90 (3.93)</td>
</tr>
<tr>
<td>Total on-ice practice per week (hr)</td>
<td>4.67 (2.99)</td>
<td>7.15 (3.45)</td>
</tr>
<tr>
<td>Synchro on-ice practice per week (hr)</td>
<td>3.58 (2.18)</td>
<td>4.68 (3.27)</td>
</tr>
<tr>
<td>Total off-ice practice per week (hr)</td>
<td>2.58 (1.50)</td>
<td>4.00 (2.40)</td>
</tr>
<tr>
<td>Synchro off-ice practice per week (hr)</td>
<td>2.08 (0.92)</td>
<td>2.65 (1.25)</td>
</tr>
</tbody>
</table>

Note: Values are expressed as mean (SD)

4.4.2 Jumping Comparison Between Groups

Stiffness: Percent Time Spent off Force Plate

The results showed no significant differences between the groups for BLH. However, the high freeskate group spent a significantly longer time off the force plate compared to the low freeskate group for LLH and RLH (Table 14).

Table 14 Percent (%) Time Spent off the Force Plate during Hopping Across Freeskate Groups

<table>
<thead>
<tr>
<th></th>
<th>Low Freeskate Group</th>
<th>High Freeskate Group</th>
<th>p-value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLH (%)</td>
<td>42.066</td>
<td>48.076</td>
<td>0.139</td>
<td>(-14.49, 2.48)</td>
</tr>
<tr>
<td>LLH (%)</td>
<td>27.143</td>
<td>34.944</td>
<td>0.0068 *</td>
<td>(-13.07, -2.52)</td>
</tr>
<tr>
<td>RLH (%)</td>
<td>27.365</td>
<td>34.096</td>
<td>0.0028 *</td>
<td>(-10.72, -2.73)</td>
</tr>
</tbody>
</table>

* p<0.05; BLH = both leg hopping, LLH= left leg hopping, RLH = right leg hopping
**Flight Time**

The results showed no significant differences in flight time between the low freeskate group and the high freeskate group for any jumping condition (Table 15).

**Table 15** Flight Time during Countermovement Jumping Across Freeskate Groups

<table>
<thead>
<tr>
<th></th>
<th>Low Freeskate Group</th>
<th>High Freeskate Group</th>
<th>p-value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLJ (s)</td>
<td>0.299</td>
<td>0.313</td>
<td>0.6445</td>
<td>(-0.07, 0.04)</td>
</tr>
<tr>
<td>LLJ (s)</td>
<td>0.244</td>
<td>0.251</td>
<td>0.722</td>
<td>(-0.04, 0.03)</td>
</tr>
<tr>
<td>RLJ (s)</td>
<td>0.258</td>
<td>0.257</td>
<td>0.975</td>
<td>(-0.04, 0.04)</td>
</tr>
</tbody>
</table>

BLJ = both leg jumping, LLJ = left leg jumping, RLJ = right leg jumping

**Peak Force Generation**

The results showed no significant differences in peak force between the low freeskate group and the high freeskate group for any countermovement jumping condition (Table 16).

**Table 16** Peak Force Generated during Countermovement Jumping Across Freeskate Groups

<table>
<thead>
<tr>
<th></th>
<th>Low Freeskate Group</th>
<th>High Freeskate Group</th>
<th>p-value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLJpeak (N)</td>
<td>1594.767</td>
<td>1573.782</td>
<td>0.911</td>
<td>(-374, 416)</td>
</tr>
<tr>
<td>LLJpeak (N)</td>
<td>1368.087</td>
<td>1303.883</td>
<td>0.6884</td>
<td>(-274, 403)</td>
</tr>
<tr>
<td>RLJpeak (N)</td>
<td>1406.157</td>
<td>1310.794</td>
<td>0.5554</td>
<td>(-253, 444)</td>
</tr>
</tbody>
</table>

BLJpeak = peak force generated during both leg jumping, LLJpeak = peak force generated during left leg jumping, RLJpeak = peak force generated during right leg jumping
Time to Stabilization

The results showed no significant differences (p=0.309, CI= -0.49, 0.16) in time to stabilization between the low freeskate group (0.621s) and the high freeskate group (0.783s) for the box drop trials.

Power Output

The results showed no significant differences in power output between the low freeskate group and the high freeskate group for any countermovement jumping condition (Table 17).

Table 17 Power Output Generated during Countermovement Jumping Across Freeskate Groups

<table>
<thead>
<tr>
<th></th>
<th>Low Freeskate Group</th>
<th>High Freeskate Group</th>
<th>p-value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLJpo (W)</td>
<td>102.07</td>
<td>109.67</td>
<td>0.631</td>
<td>(-41.57, 26.38)</td>
</tr>
<tr>
<td>LLJpo (W)</td>
<td>85.95</td>
<td>70.34</td>
<td>0.445</td>
<td>(-32.81, 64.03)</td>
</tr>
<tr>
<td>RLJpo (W)</td>
<td>76.03</td>
<td>64.36</td>
<td>0.490</td>
<td>(29.61, 52.94)</td>
</tr>
</tbody>
</table>

BLJpo = power output during both leg jumping, LLJpo= power output during left leg jumping, RLJpo = power output during right leg jumping
5. Discussion

5.1 Injury Epidemiology

5.1.1 Introduction

Synchronized skating is a newly-formed, fast-paced sport that is unique from the other three divisions of figure skating. There is currently minimal research in the area of synchronized skating, however research regarding the other three figure skating divisions can be used as a jumping off point for synchronized skating research. Research regarding ice dancing, singles skating, and pair skating have utilized retrospective and cross-sectional questionnaires as well as medical evaluations. Figure skating research usually focuses solely on elite level skaters, however this study includes skaters of five different levels, of which many different ages and abilities are included.

5.1.2 Acute and Overuse Injuries

In this study, participants were found to have had 92 injuries, 72.8% of which were acute injuries. Of the 51 injuries that were attributed specifically to synchronized skating, 68.8% were acute injuries. All teams, except for the cross-skaters, reported more acute injuries than overuse synchronized skating injuries. These findings were consistent with the results from previous skating studies. Smith & Lundington (1989) found that elite ice dancers and pair skaters reported more acute than overuse injuries (55%), with almost twice as many serious injuries caused by acute events rather than overuse. This finding is also reinforced in the Dubravcic-Simunjak et al. (2006) study, where it was found that senior level synchronized skaters sustained more acute injuries than overuse injuries.

These findings could be attributed to the fact that pair skating, ice dancing, and synchronized skating all require more than one skater on the ice, which could lead to impact injuries. In this study, multiple concussions and lacerations were reported to have been sustained by running into or falling on teammates during synchronized skating. Senior-level synchronized skating involves lifts, which are also elements in pair skating and ice dancing. Smith & Lundington (1989) reported that 10 pair skaters and 1 ice dancer sustained serious injuries from lifts. In this study, one collegiate level synchronized skater suffered a catastrophic knee injury during her career, sustaining a full ACL tear, partial MCL tear, and tib-fib fracture, as a result of being dropped from a lift. There were several head, finger, knee, and wrist injuries that were
sustained by skating or falling into teammates, some of which resulted in lacerations from the blades of teammates.

Freestyle skaters do not see this rate of acute injuries compared to overuse injuries, as evidenced by Dubravcic-Simunjak et al. (2003), which reported more overuse injuries (106) than acute injuries (65) in both male and female elite junior freestyle skaters. This is related to the excessive jumping that singles skaters do, which can result in overuse injuries such as stress fracture, sprains, shin splints, and jumper’s knee. This study reinforces the current literature by reporting a higher prevalence of acute injuries in synchronized skaters as compared to acute injuries.

5.1.3 Injuries by Body Region

Participants were found to have sustained the highest number of injuries to the head and spinal region, followed by the foot and ankle region, and thirdly the finger, wrist, and hand region. This is not consistent with the results of Smith & Ludington (1989) or Dubravcic-Simunjak et al. (2006), both of which reported head and neck injuries as one of the lowest regions of injury. However, Smith & Ludington focused on different skating divisions, while Dubravcic-Simunjak et al. focused on one season of senior-level synchronized skating and studied lower back pain as a separate region of injury. Head and spinal injuries were treated as one separate entity in this study due to the participants’ reporting of head, neck, and back injuries as exacerbating each other. For example, one novice skater reported a bilateral spondylolysis of which she said the initial injury caused a whiplash neck injury. These injuries are important to study in synchronized skating due to the unique falls and impacts that occur, such as backwards falls into other skaters, backwards impacts during pass-throughs, and being accidently thrown out of elements at high speeds, all of which could lead to head and spinal injuries.

Foot and ankle injuries were the second most reported region of injury, which was consistent with previous studies. Foot and ankle injuries, both overuse and acute, are common in figure skating and may be attributed to wearing figure skating boots and bending at the ankle in a way that is different than how you bend in everyday life. Although there was no significant differences between boot brand and injury found in this study, a study by Haguenauer et al. (2006) demonstrated that wearing figure skates, especially heavy skates, can limit one joint’s range of motion, which in turn causes a reorganization and redistribution of energy produced at
other joints. This reorganization can lead to injuries. It is thought that the newer Edea brand of skate, while lighter and softer, is too stiff and limits the mobility of the ankle and knee. This can lead to reorganization of the joints during landing and lead to fractures in the ankle and tears in the knee. Further studies are needed that focus on boot brand across the divisions of skating, as well as jumping studies that focus on grouping skaters by boot brand worn.

Finger, hand, and wrist injuries are not as commonly reported in figure skating. Wrist injuries generally occur across all divisions and are sustained when falling on a stiff arm. However, finger and hand injuries are thought to be more common in synchronized skating than in other divisions because synchronized skaters connect to each other through various shoulder, arm, and hand holds. In this study, hand, finger, and wrist injuries accounted for 16% of all reported injuries and 19.6% of synchronized skating injuries. Injuries included a broken wrist sustained from a teammate running into the skater during practice, lacerations of the finger and hand from being cut by a teammate’s blade, and a fall during synchro practice that resulted in both wrists being injured. In past studies, fingers and hands have not been looked at separately, and instead have been referred to as ‘distal’ or ‘upper extremity’. This study is one of the first to look at wrist, finger, and hand injuries as unique injuries to synchronized skaters.

5.1.4 Test Level

This study found a significant difference in synchronized skating injury across test level. The difference was specifically between the MIF juvenile through intermediate group and the novice through senior group. This finding suggests a jump in injuries when reaching the novice MIF test level. All junior and senior level skaters, the two highest levels, must have passed the novice MIF test to participate, however junior and senior level skaters were not included in this study. Many synchro programs have their own internal testing standards, some of which require much higher than the USFSA requirements. For example, in this study all collegiate skaters passed their senior MIF tests, and some of these skaters skated on junior and senior level teams before joining the team in college. This leads to the thought that it is not the MIF level that is a risk factor, but rather team level and difficulty. Although there were no significant differences found between team level and injuries in this study, future synchronized skating research should include every team level for comparison.
5.1.5 Concussions

Concussions have recently been in the forefront of major American sports such as football and hockey. Figure skating is also going through its own concussion crisis, as major American skaters Ashley Wagner and Joshua Farris have been open about their struggles with concussions. Joshua Farris’s career ended due to multiple concussions which lead to a myriad of issues such as anxiety, depression, and physical eye issues that resulted in a herniated disc. Like many sports, concussions are not openly talked about and can be seen as something that athletes need to power through.

There were 11 concussions reported, with 2 skaters reporting multiple concussions. There were no significant differences between concussions and age, team level, practice time, or years skating, however there was a significant difference between boot brand. Specifically, there was a difference between Edea and Jackson boots, with Edea-wearing skaters sustaining significantly more concussions. As previously mentioned, this could be attributed to the stiffness of Edea boots, which leads to poor ankle bend. Poor ankle bend can lead to backward falls, due to the rocker of the blade. However, due to the small number of concussions reported, future research needs to be done in the area of concussions. Specifically researching skaters with concussion history could lead to a more conclusive link between concussions and certain risk factors.

5.2 Off-ice Jump Landing Variables

Previous research has reported that when comparing the vertical ground reaction forces of freestyle skaters with non-skaters, it was found that skaters had a greater normalized peak GRF, a shorter time to peak GRF, and a shorter time to stabilization (Saunders, Hanson, Koutakis, Chaudhari, & Devor, 2014). This gives evidence to the idea that freestyle skaters are putting significantly more force on their bodies than non-skaters, and that this force could directly lead to injury. However, there have not been jumping studies with synchronized skaters or comparison between jumping levels. This study’s jumping portion aimed to compare jumping variables between synchronized skaters with and without high level freestyle skating levels. The high freestyle group included skaters that had passed their juvenile freeskate test or above, since juvenile is the test level where an axel jump is required.

The results of this study showed that the high level freeskate group spent a significantly longer time off the force plate compared to the low level freeskate group for LLH and RLH. The
difference in ‘stiffness’ may be because skaters with high level freestyle skills have a quicker release into jumps, as this is a skill needed when jumping in combination. Skaters that are not jumpers may ‘stick’ more to the ice because they do not have the quick, spring-like reaction from takeoff to jump. There was no significant difference between groups and BLH, which could be because hopping on both legs is a skill skaters learn very early on, whereas hopping on one leg is gained early on only if the skater is preparing for jumping.

There was no significant difference in flight time between the groups. This may be surprising to some skaters and coaches since flight time is a very important part of jump technique, because the more time a skater is in the air, the more rotations they can complete. However, jumping is also about rotational speed and snap into the rotation, not just flight time. Some high-level freestyle skaters have large jumps with a long flight time, however they have poor rotational speed or a delay into rotation, which leads to incomplete rotations and falls. Future research is needed that compares the flight time and rotational speed of synchronized skaters across various jumping levels.

The results showed no significant differences in peak force between the low freeskate group and the high freeskate group for any countermovement jumping condition. There have been no previous skater to skater studies, however Saunders et al. (2014) found that skaters had a greater peak force than non-skaters. It could be expected that the low freeskate group would have a significantly lower peak force because jumpers are used to landing with more force than non-jumpers, who also tend to have worse jumping technique. However, further studies with more participants and perhaps a larger breakdown of jumping level is needed.

The results showed no significant differences in time to stabilization between the low freeskate group and the high freeskate group for the box drop trials. Like peak force, it could be expected that low freestyle skaters have a higher time to stabilization, due to the lack of repetition in jumping and generally poorer technique, which can lead to wobbling. However, box drops are a fairly simple exercise, and many skaters include box drops as part of an ice off regimen. Box jumps also do not involve rotation, which is where the stabilization comes into greater play when skating. Perhaps a jumping exercise with rotation involved would provide a more accurate representation of time to stabilization.
5.3 Limitations and Future Research

There are several limitations to this study. The epidemiological questionnaire portion would have benefited from more participants in several team levels, especially teams that included older skaters. Although there have been limited studies comparing different synchro team levels, there are several lower level teams that were not included. Future research could include planned visits to synchronized skating competitions so full rosters of multiple teams could be included.

There was also no general guideline of what should have been defined as an “injury”. Some previous research regarding sports outside of skating have only included injuries which resulted in a missed practice, such as a football or hockey team practice. However, skating is unique in the sense that skaters practice for hours outside of rigid team practices. Many skaters are involved in more disciplines than just synchronized skating, and those other disciplines do not have team practices because there is no team; it is all individually based, and hours are set by the individual skater. In this study, the “missed practice” section was answered in weeks, however this may not lead to an accurate sense of how much time was truly missed, since skaters practice for varying hours during the week, as do synchronized skating teams. Therefore, the definition of “injury” was left up to the skater. Some skaters reported sprains as injuries, because it impacted their skating, whereas some skaters did not, because it was seen as soreness, rather than an injury. Future research should utilize a uniform definition of injury, as well as a more accurate way of describing “time missed” when talking about non-team practices.

The jumping portion had limitations as well. The biggest limitation was the number of participants. Due to the injuries that occurred to the participants of the two teams, the timing of the study compared to the competition season, and the voluntary basis of the study, the number of participants were fewer than intended. More participants from multiple team levels could potentially reveal more significant differences in measurements, particularly power and peak force.

Future researchers could look at a different way of dividing jumping level. While using freeskate test level, as was done in this study, is a reliable and uniform way of dividing levels, not all skaters jump at their passed freeskate test level. For example, some skaters jump at a higher level than their test level but do not test up because they do not want to compete at a higher level. The required elements in freeskate tests are lower than those actually competed in
the respective competition level because the tests are designed to ensure that skaters can complete the minimum elements required before competing. On the other hand, some skaters cannot jump at the level of the test they passed. This could be due to passing the test years before and those jumps being unattainable in present time, which is common with adult skaters. It could also be due to skaters having a good skate on their test day, but not being able to replicate those jumps consistently. For these reasons, future researchers could potentially interview skaters on what jumps they can consistently complete and then divide jumping based on the responses. This would ensure that skaters are not divided into a group where they are at a much different level than the other participants.
6. Conclusion

The current study creates a clearer picture of the unique injuries that synchronized skaters face by including synchronized skaters of many different competition levels, something that previous research has not included. The data reveals a higher prevalence of acute injuries and injuries of the head, knee, and hand in synchronized skaters. The hand, finger, and wrist injuries seem to be sustained by synchronized skaters at a higher rate than freestyle skaters, when compared to past skating studies. This could be due to the multiple skaters that are on the ice, coupled with lifts and other difficult elements that are completed at high speeds. However, it is not clear whether these injuries are consistent for skaters of different synchro levels, and thus difficulty levels, or if it is due to the skill level of the skater herself. More research is needed that includes more participants across team levels.

This study also adds to the limited literature on jumping forces of figure skaters, focusing solely on synchronized skaters. This study revealed a significant difference in time spent off the force plate during metronome hopping, when hopping off both feet individually, which was used as an indication of ‘stiffness’. This leads to the thought that synchronized skaters with a higher jumping background may have the ability to leave the ground faster during landings, which is a skill needed by all skaters who jump. Future research should include more participants from different jumping backgrounds and skating divisions to get a full picture of how jumping affects different landing variables.
7. References


Hollingshead, T. (2014). *Figure 8: Skaters feel eight times their body weight when they land a jump.* Retrieved from: www.news.byu.edu.


