The prevalence of back injuries amongst figure skaters in relation to their functional movement

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THE PREVALENCE OF BACK INJURIES AMONGST FIGURE SKATERS IN RELATION TO THEIR FUNCTIONAL MOVEMENT

by

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THE PREVALENCE OF BACK INJURIES AMONGST FIGURE SKATERS IN RELATION TO THEIR FUNCTIONAL MOVEMENT

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Boston University School of Medicine, 2013

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ABSTRACT

The high incidence of back injuries amongst competitive figure skaters is reason for concern. Little is known regarding on or off ice factors contributing to these types of injuries. Insight into the causes is essential for recommending changes to prevent back injuries, to make skaters more productive with their training and improve their skating. The uniqueness of figure skating requires an in-depth look at all aspects of their training in order to understand what might be causing these injuries to occur.

The goal of this study was to evaluate members of the Skating Club of Boston (SCOB) training community for the on and off ice training patterns and movements and compare those skaters with repeated injuries to those who are uninjured. In this study, 34 competitive figure skaters were enrolled, and divided into categories of skaters with significant back injury history (BIH) and skaters with no back injury history (NBIH) and stratified by gender. All skaters completed an injury history questionnaire, an off-ice muscle strength and flexibility assessment, an off-ice analysis of a squat movement and an analysis of on-ice jump technique.
Males with BIH were overall older, had skated more years and had higher vertical jumps both on and off the ice but showed no differences in upper body strength/flexibility and core strength compared to NBIH skaters. During the squat analysis, the men with BIH had less knee flexion and a greater angle leaning forward when wearing skates as compared to sneakers and compared to the men with NBIH. This pattern suggests that the men with BIH appear to be unable to get deep into their knees during a static, isometric movement, irrespective of their footwear. With on-ice jumping, the men with BIH showed less ankle bend, more knee bend, and greater bend forward during the take-off and greater hip flexion on the landing. They are therefore struggling to stay upright during their take-off and landing positions. Their greater knee flexion, although opposite to what was found in the squat analysis, might be the only way for the men with BIH to control their jump landings. This motion repeated day after day may be a major factor that contributed to their back injuries in the first place. Aspects involving their trunk core strength and stability might be causing the men with BIH to have such poor motion. Moreover, even though they are stronger, by continuing these habits and setting no jump maximums for themselves, these skaters might be prone for more injuries in the future. Therefore the men with BIH appear to be overall stronger, but unfortunately more vulnerable to injury due to their lack of proper mechanics when performing jumps on the ice.

The females with BIH were overall much stronger than the group with NBIH. Firstly, they were older and had skated for more years. They performed more hours of off-ice training, warm-up and overall training time. They also showed better training habits as more females with BIH warmed-up before every session and cooled-down after every session. The females with BIH also showed stronger core stability and
strength while completing side planks and the Kendal Double Leg Lowering assessment. During the squat analysis, the females with BIH had very little change in position from sneakers to skates despite the lack of ankle mobility. The females with NBIH actually performed the same amount of ankle flexion and showed slightly more knee flexion, but bent more at the hips and leaned forwards more with their upper body. Compared to the females with NBIH, the group with BIH stood more upright during this movement. With landing jumps on the ice, the females with BIH showed better landing mechanics as they had greater ankle and knee flexion and showed less hip flexion and a more upright landing position as compared to the females with NBIH (who showed more bend forward and less knee flexion during landing). These two groups showed no significant differences during their take-off positions. These findings suggest that the females with NBIH are not strong enough overall and are compensating during their landing positions. This group might therefore be more vulnerable because of their lack of strength and their awkward landing biomechanics, thus leading to a greater risk for back injuries.

The conclusion from our study is that the men with BIH are vulnerable to future injuries but the females with BIH are actually much stronger overall than the females with NBIH. Our findings suggest that some of these aspects make the females with NBIH prone to injuries in the future.
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LIST OF ABBREVIATIONS

BIH  Back injury history
FL   Free leg
LL   Landing Leg
NBIH No back injury history
SCOB Skating Club of Boston
INTRODUCTION

Skating on ice is an activity that has been around for thousands of years. It was initially used as a means to travel in Scandinavian countries. Centuries later, long distance skating became a recreational activity in the Netherlands. In the mid-seventeenth century modern day figure skating developed in England (Hines, 2006). Currently, there are three competitive Olympic figure skating events: singles, pairs and ice dancing. Each discipline requires different skills and strengths. Competitors in singles compete by themselves and focus on completing jumps and spins. Pairs skating has fewer jumps and spins but includes more dangerous elements such as throws, twists and lifts. Ice dancing has no jumps and incorporates more intricate movements and step sequences.

All three disciplines in skating involve the entire body and consist of numerous unilateral repetitive twisting and turning motions. These movements can cause skaters to develop asymmetries in muscle strength and flexibility. For example, in single and pairs skaters the quadriceps muscles are generally more developed in the landing leg versus the extended free leg (Smith, 1997). These imbalances can make skaters more vulnerable to injuries. An initial study from the 80s concluded that skaters averaged 1.84 serious injuries per 1000 exposure hours (Smith and Micheli, 1982). However, other studies from the same time have shown ranges from 0.27-0.35 injuries per 1000 exposure hours of training (Brock and Striowski, 1986; Brown and McKeag, 1987). A Danish study from the 1990s showed that skaters averaged 1.37 injuries per 1000 hours of training (Kjaer and Larsson, 1992). Entering the 2000s, skaters were found to incur 0.83 injuries a year or 1.37 injuries over an entire career (Dubravcic-Simunjak et al., 2003; Fortin and Roberts, 2003). Finally, during the two week period of the 2010 Winter
Olympics in Vancouver, Canada, 14% of the competitors sustained an injury either in practice or in competition (Engebretsen et al. 2010).

Over the past 15 years, the sport of figure skating has changed immensely. In 1999, the International Skating Union removed ‘figures’ from competition and in 2004 implemented a new judging system. Figures, or school figures, required skaters to practice circular patterns on one foot for several hours a day and taught skaters how to maintain and master balance, control, flow and edges (US Figure Skating Special Regulations for Figures, n.d.). At the same time, the United States Figure Skating Association implemented ‘moves in the field’ tests and placed a higher demand for increased technical and choreographic difficulty for all levels and disciplines (Lawless et al., 2010). Although somewhat similar to school figures, ‘moves in the field’ tests are rarely practiced and are not as time-intensive as figures used to be.

Because of these major changes, experts in the sport working regularly with elite skaters have suggested that the injury rate has increased (Geminiani and Cook, personal communication, March 2013). Brian Boitano, the 1988 Olympic Mens Gold medalist, as quoted by Waldman (2006) suggested that injuries have increased since his time because he used to ‘practice compulsory (figures) 4 1/2 hours a day’ and skaters did not ‘have time to thrash our bodies as much’. Others have suggested that a higher incidence of injuries in skaters may result from more difficult elements being attempted by younger skaters as well as because the amount of training may have become too much for skaters (Aleshinsky, 1998). This hypothesis stipulates that more skaters are having overuse injuries rather than injuries due to inadequate strength and conditioning. This concept is supported by studies from Bloch (1999) and Lawless et al (2010) who found that most injuries occurring in competitive single skaters training many hours per
week were considered overuse injuries. However, pair skaters and ice dancers were found to have more acute injuries (Smith and Ludington 1989).

**Overview of Previous Studies**

Previous studies have primarily examined the incidence of injuries and basic reasons for pain amongst figure skaters. Certain areas of inflexibility along with inadequate muscle development seem to be the major contributing factor to their injury rate. Although serious injuries to pairs skaters are often acute and not preventable, Smith and Ludington (1989) concluded that 4 out of 33 injuries seen during their study could have been prevented if skaters had greater strength and flexibility in relevant muscle groups (Smith and Ludington, 1989). In a roundtable discussion, Dr. McQueen stated that knee pain seen in national level junior skaters stemmed from inflexibility in the quadriceps muscle, and that increasing flexibility of this group of muscles lowered the incidence of knee pain while those that had less flexibility had increased knee pain. (Aleshinksy et al, 1988).

Building on the relationship between the knee and the quadriceps, the occurrence of back pain has a similar flexibility and strength component. Micheli and Smith (1982) concluded that there was a relationship between tight lumbodorsal fascia, tight hip flexors and low back pain. They also concluded that lack of flexibility in the hamstrings could also lead to lower back pain. A combination of lack of strength seen in the abdominals or lower back muscles was also a possibility. A study by Porter et al (2007) concluded that lower back pain may be caused by lumbar strains, facet pain, posterior iliac crest injuries, spondylolysis or spondylolisthesis. These injuries appeared to be related to the stiffness of the skater’s boot. They noted that increased rigidity in
skates limits ankle and knee motion causing skaters to increase flexion at the hips and extend the back to maintain balance. Wearing skates forces competitors to modify the coordination of their movements in order to adapt to the limited range of motion in their ankles. These modifications in biomechanical movements during jumping may cause skaters to compensate with other parts of their bodies in order to achieve their desired movements. Noe et al (2007) suggested that skiers, who have similar limited ankle motion as skaters, actually exploit and take advantage of the additional support of their equipment in order to help better control their posture while in different balancing conditions. However, this adjusting by skiers was not compared to their injury rate. Other studies have noted that jumping with skates causes more work to be done at the hips and less work by at the knee and ankle joints (Haguenauer et al, 2006). This increased work by the hips might be a modification causing skaters to become more vulnerable to back injuries.

Fortin and Roberts (2003) reported that with competitive figure skaters, 15% of the injuries occurring during training are back injuries. Of trunk injuries experienced in skaters, it is predicted certain maneuvers might be more problematic such as the hyperextension created during the layback spin and the flip and lutz jumps where the upper body bends, extends and twists against a fixed toe pick (Bloch, 1999). The Children’s Medical Center at Legacy Ambulatory Care Pavilion also noted that the repetitive motions in figure skating were causing back pain because of the required continuous hyperextension and hyperflexion of the back and sudden changes in motion (Figure Skating Safety: A Parent’s Guide for Getting Kids back in the Game, n.d.). Dr. Mark Adickes was quoted in the Houston Chronicle that he believes ‘the jarring from landing jumps, more than falling, puts a tremendous amount of stress on the hip and
back. And because skaters land on the same leg jump after jump, years of training can damage the spine’s alignment’ (Sewing, 2010).

A conclusion of these past studies has been that most back injuries are caused by overusing relevant muscle groups. Overuse injuries are defined as ‘sports-related microtraumas that result from repetitively using the same parts of the body’ (Yen, 2012). Figure skaters will always have to train the same specific movements in order to perfect them, so they must learn to find balance between training efficiently to improve (over-reaching) versus over-training and causing an injury to occur. Finding the optimal combination of training on the ice, off the ice, resting and other activities to produce fewer injuries with the best results should be a major focus of research.

**Rationale for the present study**

The high incidence of back injuries amongst skaters is reason for concern. More must be done to protect skaters from these types of injuries. By finding ways to prevent back injuries, skaters can be more productive with their training and improve their skating. The uniqueness of figure skating requires an in-depth look at all aspects of their training in order to understand what might be causing these injuries to occur. No published studies have combined all aspects of figure skating together to find reasons for injury patterns. A combination of comparing the functioning of different muscle groups, their training patterns and their jump technique to their injury history is necessary. Assessing their jump technique and injury exposure will allow us to make recommendations for future athletes by promoting wellness via injury prevention once risk have been identified - specifically strength, flexibility and neuromuscular deficits/imbalances.
The goal of this study is to look at members of the Skating Club of Boston (SCOB) training community and compare the on and off ice training patterns of those skaters with past injuries to those who are uninjured. By comparing these two groups, we suspect we will find specific imbalances in muscle strength and flexibility and/or different hours of training that might be contributing to injuries. By incorporating biomechanical data in skates on and off the ice, we hope to create more accurate data for establishing differences between skaters. We anticipate this data will allow us in the future to create more age-appropriate training regimens for skaters and promote safer training and skill growth while lowering the incidence of injuries.
**Hypotheses**

Primary hypothesis: Skaters with back injuries will have significantly different training patterns and physical attributes as compared to those without a history of back injuries. They will also have significant differences in their mechanical movements on and off the ice.

Specifically:

1. Skaters with back injury histories will do significantly less warming up, less cooling down, less stretching, more jump attempts, fewer physical activities outside of skating and less amount of training off the ice.

2. Skaters with back injury history will perform significantly fewer push-ups, not hold the side plank for as long a period of time and will have a lower vertical jump. They will be significantly less flexible in all lower and upper body tests. Lastly, they will have significantly less strength in their hips and abdominals. Upper body strength will not be significantly different.

3. Skaters with back injuries will have similar biomechanical chain of movements on and off the ice. With the off-ice squat analysis, skaters with back injuries will have greater flexion at the hips and knees in both sneakers and skates. Similar results will be seen on the ice.

4. Skaters with back injuries will have more prominent asymmetries in strength and/or flexibility.
Specific Aims

The main objective of this study was to determine if a skater’s training pattern and functional biomechanical mobility in terms of muscle strength and flexibility affect his/her jump technique and the likelihood of sustaining a back injury. We therefore collected quantifiable data by looking at both the on and off-ice movement patterns along with testing the strength and flexibility of different muscle groups to see where specific imbalances might be increasing skater’s vulnerability to injury.
METHODS

Study Design

This study primarily used a quantitative, observational study design although some qualitative data was also collected. The first part of the study involved a questionnaire about basic skating information, current training habits and a retrospective injury history. Many of the questions were quantitatively-based but the skaters were also asked to elaborate in their own words to establish how individual skaters perceived each question. The second section assessed skaters using muscle strength and flexibility tests off the ice in both sneakers and in skates. The final testing was a video analysis of on-ice jumping technique with three different jumps. The Institutional Review Board at Boston Children’s Hospital reviewed the project and granted ethical approval.

Participant Selection

The targeted participants of this study were competitive figure skaters, aged 10-25, training at the Skating Club of Boston (SCOB). Participants included both males and females competing in either singles or pairs figure skating. Dancers were not included because: 1) the SCOB does not have any current competitive dancers training at their facilities and 2) dancers experience different levels of vertical and torsional forces compared to singles and pairs skaters due to the fact that they do not jump. The exclusion criteria for this study were skaters who were currently injured and would not be able to complete the different study sections.

All skaters recruited were, at the time of the study, members of the United States Figure Skating Association. Competitive skaters were defined as skaters competing at regional, sectional, national and/or international events and training at least 10 hours a
week. All participants practiced at the SCOB facilities and were familiar with the surroundings. The SCOB was the only training facility chosen because of the large number of potential participants currently training at the club. The SCOB had 62 members who competed at the 2012 regionals, sectionals and nationals (IceNetwork, 2013). Of these competitive skaters, ten are current members of the United States National team (US Figure Skating, 2013).

Prior to the study, an introductory letter was delivered to the coaches of potential participants informing them of the study (Appendix A). This letter was approved and signed by the head of the SCOB before it was sent to the coaches. Flyers were placed at the SCOB and a desk was set up with a sign-up sheet for those interested in participating. All skaters fitting the inclusion and exclusion criteria were invited to participate in the study and if they agreed written informed consent was obtained. If the skater was under the age of 18, he/she was asked to sign an assent form and their parent/guardian was given the consent form (Appendix B). Skaters who choose to participate were assigned a unique 3 digit Study ID number.

After recruitment, 34 skaters agreed to participate in the study. These skaters were split into two groups – those with back injury history (BIH) and those that had no injury history (NBIH) (12 and 22 skaters, respectively). Any ambiguity of back injury history was evaluated by the principal investigator to decide which group that individual skater would be entered in. The definition of a back injury was having had either pain or an injury to the back that had forced the skater to miss more than five days of training, adjust training to a lighter intensity for 5 days and/or required medical treatment before resuming full activity again.
Description of Study Procedures

This study included three segments: the retrospective questionnaire, the individual muscle strength and flexibility tests and the on-ice jumping video analysis. It took approximately forty-five to sixty minutes to complete the entire assessment. This was a one-time testing session completed at the SCOB with no follow up testing. All off-ice testing was completed in a private room in order to ensure each participant’s privacy.

Questionnaire

The retrospective questionnaire (Appendix C) asked about age, gender, basic skating information, training habits and injury history. The main focus of the study was on back injury history but skaters were also asked to list all other injuries that had occurred over the past five years. This was done to ensure that skaters without significant back injuries could provide additional information that might be important. The questionnaire was created by the research team which included the head physician at the SCOB and the head athletic trainer. To ensure validity, three skaters were selected to look through the questionnaire before the study started for clarity purposes but no changes were needed. Skaters were asked to fill out the forms either alone or with their parents and provide as much detail as possible. Skaters took approximately ten minutes to complete all the questions. The research team was available if there were any questions that needed clarification.
Flexibility and Strength Assessment

After completion of the injury history questionnaire, each participant was taken through their individual muscle strength and flexibility assessment (Appendix D). The muscle assessment tested different muscle groups and compared the strength and flexibility of both sides of the body to look for imbalances and/or areas of dysfunction. This assessment was mostly performed in sneakers but the final portion was performed while wearing skates with skate guards on. The entire assessment took twenty-five minutes.

The first part of this assessment gathered simple background information such as height, weight, number of push-ups performed correctly and the time a side plank was held correctly. All heights and weights were collected from the same machine. Push-ups were performed by having the skater start in a two-handed plank and perform as many push-ups as possible. The mark for going down was a 90 degree bend of the elbows (see Figure 1). Side planks were performed on the dominant side of the body (the side that the skater said was their writing hand). Skaters were asked to maintain a straight body position and hold their body weight with their arm bent and perpendicular to the floor for a maximum of two minutes (see Figure 2). Demonstrations were made if the skater was unclear with the positioning for either the push-up or the side plank. A jump mat (Just Jump System, Probotics Inc., Huntsville, AL) was used to measure the height attained during a vertical jump with two feet, the left foot and the right foot. Skaters were asked to perform each vertical jump three times and the average number was taken. A 30 second break was given in between each two foot jump in order to allow sufficient recovery. A 10 second break was given in between each one foot jump.
Figure 1. Push-up position. The skater was asked to start in the upright position and bend until the elbows reached a 90 degree angle.

Figure 2. Side-plank position. Skater was asked to maintain this position for a maximum of two minutes.

The flexibility section of the muscle assessment required each skater to wear socks or tights while measurements were taken with a goniometer. Only one trained individual made the measurements with the goniometer for consistency purposes. The flexibility (assessment focused on muscle groups relevant to proper spinal alignment) tests were based mostly around muscles that had insertion or origin points close to or
near the spine and hips. Both the free leg (FL) and landing leg (LL) side of the body were tested.

To begin, with the knees straight, the skater’s passive ankle plantar flexion and passive dorsiflexion was measured in sneakers (see Figure 3). To look at hip flexibility, legs were kept straight while left and right sided single leg flexion was measured with the skater supine and extension with the skater prone (see Figure 4). Hip abduction was also tested with the skaters supine (see Figure 5). The final test for hip flexibility was completing the Thomas test. This test was based on a pass/fail scale and was performed by placing the skater supine with one leg straight and the opposite leg tight to the chest (see Figure 6). If the extended leg remained in a stationary position on the table, the skater was given a ‘pass’. If the leg rose or extended, the skater was given a ‘fail’ (Peeler and Anderson, 2008). A ‘fail’ was indicative of tight iliopsoas, rectus femoris and/or tensor fascia lata (Gross et. al. 2001). The lower back was kept on the surface of the table during this test.

![Figure 3. Passive Ankle Movements. A. Dorsiflexion B. Plantar flexion. This image shows the two angles being measured for ankle flexibility.](image-url)
Figure 4. Passive Hip Flexion (supine) and Passive Hip Extension (prone). This image shows the two angles measured for hip flexion and extension, respectively.

Figure 5. Hip Abduction (supine). Movement performed during hip abduction test and angle measured. The dotted lines indicate the starting position of the leg.

Figure 6. Thomas Test (Prone). Position achieved during the Thomas Test.
The other lower body flexibility tests conducted were for the quadriceps muscles and the iliotibial bands. The quadriceps were tested by placing the skater in a prone position and pulling the foot towards the buttocks and measuring the angle at the knee (see Figure 7). Iliotibial band flexibility was assessed using the ITB/Ober Test (Khaund, 2005). This test required the skater to lie on one side with the lower hip and knee at a 90 degree angle. The upper leg is abducted, the knee is flexed and the hip is extended (allowing the iliotibial band to move posteriorly over the greater trochanter) (See Figure 8). If the leg remains in an abducted position, the skater would be given a ‘fail’ as this indicated a tight iliotibial band. If the leg adducted the skater would be given a ‘pass’ as this indicated a normal iliotibial band (Khaund, 2005).

![Figure 7. Quadriceps Flexibility Angle (prone).](image7.jpg)

This image shows the angle measured to determine quadriceps flexibility.

![Figure 8. ITB/Ober Test.](image8.png)

Depiction of the Ober test. Lowering of the leg will indicate whether the iliotibial band is tight or not. (Figure taken from Gross et. al, 2002)
The two upper body measurements completed were shoulder internal rotation and arm abduction. Shoulder internal rotation was completed standing and measured the angle between the body and the arm rotated in without the elbow moving (see Figure 9). Arm abduction was completed by the skater starting their hand by their side and raising it in the frontal plane until there was no more movement. This movement angle was then measured (see Figure 10).

![Figure 9. Shoulder Internal Rotation Test.](image)
The angle measured during shoulder internal rotation. The dotted arm indicates the starting position for the test.

![Figure 10. Arm Abduction Angle.](image)
This measurement required the skater to stand upright and abduct the arm away from the body.

The next section analyzed biomechanical movements during a two foot squat. Participants were asked to hold their hands above their heads and then, keeping their
feet shoulder width apart, squat down as low as possible. This section was videotaped in order to measure all the appropriate angles at the hips, knees and ankles (see Figure 11). The angle of their back compared to a vertical plane was also measured. This was completed in skates and sneakers and analyzed using Ubersense Video Coach software (Ubersense Inc., Boston MA).

![Diagram of angle measurements for squat analysis]

**Figure 11. Angle Measurements for Squat Analysis.** This image shows the angles measured during the squat analysis with skates and sneakers on.

The final off-ice assessment was the muscle strength testing. Skaters were tested using a 0-5 scale (see Table 1). Both the LL and FL sides of the body were tested. Hip strength was evaluated by placing the leg in a neutral position and offering resistance against adduction, abduction or extension. The same process was completed for ankle strength of plantar flexion, dorsiflexion, eversion and inversion.

<table>
<thead>
<tr>
<th>Score</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No contraction detected in the muscle.</td>
</tr>
<tr>
<td>1</td>
<td>Completes partial range of motion in horizontal plane. No visible movement of the part, but examiner may observe or palpate contractile activity in the muscle.</td>
</tr>
<tr>
<td>2</td>
<td>Completes partial range of motion against gravity, and moves through complete range of motion in horizontal plane.</td>
</tr>
<tr>
<td>3</td>
<td>Completes full range of motion against gravity, and holds test position with slight or no added pressure. There may a gradual release from test position.</td>
</tr>
<tr>
<td>4</td>
<td>Completes full range of motion against gravity, and holds test position against moderate to strong pressure.</td>
</tr>
<tr>
<td>5</td>
<td>Completes full range of motion against gravity, and holds test position against strong pressure.</td>
</tr>
</tbody>
</table>
To look at differences in upper body strength, we tested several muscle groups primarily near the upper back. These muscles included the deltoids, supraspinatus, infraspinatus, subscapularis and serratus anterior muscles. Descriptions of these tests are summarized in Table 2.

**Table 2. Upper Body Strength Tests**

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Position</th>
<th>Researcher</th>
<th>Skater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deltoids</td>
<td>Arms abducted to 90 degrees, elbows flexed to 45 degrees</td>
<td>Pushes down on elbows</td>
<td>Pushes up</td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>Arms extended out at 40 degrees, thumbs up</td>
<td>Pushes down</td>
<td>Pushes up</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>Arms at side, elbows bent to 90 degrees</td>
<td>Prevents external rotation</td>
<td>Pushes out</td>
</tr>
<tr>
<td>Subscapularis</td>
<td>Arm flexed and placed behind back</td>
<td>Keeps arm in</td>
<td>Pushes out</td>
</tr>
<tr>
<td>Serratus Anterior</td>
<td>Shoulder flexed, arm extended in front</td>
<td>Pushes arm in</td>
<td>Resists motion in</td>
</tr>
</tbody>
</table>

The last muscle strength assessment was for abdominal and external oblique strength and was tested using the Kendall double leg lowering assessment (Kendall et al, 1993). This test had the skater lying supine with their legs directly vertical in the air. The tester placed their hand under the lower back to confirm contact with the table. With the legs straight, the skater was asked to lower their legs until their pelvis rotated anteriorly and their lower back came off the tester’s hand (Kendall et. al, 1993). The angle of the legs compared to the ground is measured (Figure 12). The start of the test was considered 90 degrees and the maximum score was 0 degrees (when the legs were horizontal and touched the table).
Figure 12. Kendal Double Leg Lowering Assessment. This image shows the angle measured during the testing of the abdominal muscles. Note: the tester will have their hand under the lower back to find the appropriate value.

On-ice Jumping

The filming of participant’s jumping took place during his/her regular training hours. Each skater was asked to perform three different jumps. The three jumps selected were the axel jump, the loop jump and the lutz/flip jump. All three have different take-off entrances but the same landing position. The axel jump starts off from a forward outside edge. The loop jump starts off from a backward outside edge. The lutz/flip jump starts from a backwards outside or inside edge, respectively and requires a skater to pick in with their opposite foot and vault into the air. All landings are on the backwards outside edge. Each skater was asked to perform either a single, double or triple of each type of jump but only if they felt comfortable completing it. The jumps were videotaped using high speed cameras and later analyzed using Dartfish Video Analysis software (Dartfish Inc., Fribourg, Switzerland) and entered into the database. The values measured were similar angles as calculated during the off-ice squat analysis except on individual legs (landing vs. take-off) (See Figure 13).
Data Analysis Plan

Participants were screened and surveyed in regard to their biomechanics, strength, flexibility, training habits, and injury history. The results of the off-ice muscle and biomechanical assessment were correlated with the results found in the questionnaire and the biomechanics on the ice. The trends we found were used to describe a biomechanical profile of ice-skaters as well as evaluate for variance to assess if individual skaters are at increased risk of injury. The results were correlated with injury history, nature of injuries, identified deficits, hours of on and off ice time/week, and years of experience. Data was stratified by gender in order to prevent any biases that might occur between the two sexes. To determine if there were significant differences between groups, t-tests were used. For yes or no questions, the chi-squared test was used.

All questionnaire forms and data files were initially stored in a folder before it was transferred into a Microsoft Excel Database on an encrypted computer. Data was
entered once and then checked over a second time to ensure no mistakes were made during transfers. All data points taken from video were saved on a frame-by-frame basis. All video was de-identified and will not be released for any purpose.

The independent variables were the results of the questionnaire, strength/flexibility assessment and the jump technique analysis. From these variables, the potential risk factors for future or recurrent back injury were determined.
RESULTS

Skater Training Patterns

Table 3 describes the basic demographics and training patterns in male and female skaters with back injury history (BIH) and with no back injury history (NBIH). In males, the group with BIH had skated significantly more years than the group with NBIH (p<0.05). Consistent with this finding, the mode skating level for males with BIH was the senior level while for the males with NBIH it was the novice level. The men with BIH performed more hours of off-ice training and total training time than the men with NBIH. The two male groups had otherwise no significant differences. For the female groups, the skaters with BIH did significantly more hours of off-ice training, warming-up and overall training time (p<0.05). The two female groups had no other significant differences.

Table 3. Basic Demographics and Training Patterns of Skaters

<table>
<thead>
<tr>
<th></th>
<th>Male BIH (N = 5)</th>
<th>Male NBIH (N = 4)</th>
<th>Female BIH (N = 7)</th>
<th>Female NBIH (N=18)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>20.8 ± 2.9</td>
<td>16.8 ± 3.3</td>
<td>17.4 ±3.2</td>
<td>14.8 ± 2.6</td>
</tr>
<tr>
<td>Weight (lbs)</td>
<td>152.6 ± 14.5</td>
<td>136.4 ± 31.0</td>
<td>105.1 ± 9.8</td>
<td>109.1 ± 19.6</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173.8 ± 3.1</td>
<td>174.2 ± 11.1</td>
<td>157.8 ± 5.9</td>
<td>157.5 ± 8.9</td>
</tr>
<tr>
<td>Skating level (mode)</td>
<td>Senior, (4/5)</td>
<td>Novice, (2/4)</td>
<td>Senior, (3/7)</td>
<td>Junior or less, (15/18)</td>
</tr>
<tr>
<td>Number of years skating</td>
<td>15.4 ± 3.4 *</td>
<td>10.3 ± 1.9</td>
<td>12.1 ± 3.4</td>
<td>9.7 ± 3.1</td>
</tr>
<tr>
<td>On-ice hours/week</td>
<td>14.0 ± 1.7</td>
<td>11.6 ± 2.3</td>
<td>14.2 ± 1.4</td>
<td>13.1 ± 2.8</td>
</tr>
<tr>
<td>Off-ice hours/week</td>
<td>8.0 ± 2.5</td>
<td>3.1 ± 2.1</td>
<td>6.1 ± 1.7*</td>
<td>4.4 ± 1.2</td>
</tr>
<tr>
<td>Other activities (hrs)</td>
<td>1.6 ± 2.3</td>
<td>1.8 ± 1.8</td>
<td>2.4 ± 2.6</td>
<td>0.8 ± 1.8</td>
</tr>
<tr>
<td>Total training time (hrs)</td>
<td>23.6 ± 4.7</td>
<td>16.8 ± 2.2</td>
<td>22.8 ± 3.9*</td>
<td>18.2 ± 3.0</td>
</tr>
<tr>
<td>Hours warming-up/week</td>
<td>2.4 ± 0.9</td>
<td>1.5 ± 0.8</td>
<td>3.1 ± 1.2*</td>
<td>1.6 ± 1.5</td>
</tr>
<tr>
<td>Stretch/week</td>
<td>6.0 ± 3.8</td>
<td>4.6 ± 1.6</td>
<td>7.1 ± 2.1</td>
<td>6.1 ± 4.1</td>
</tr>
<tr>
<td>Competitions/year</td>
<td>6.9 ± 2.0</td>
<td>4.9 ± 1.2</td>
<td>7.2 ± 2.1</td>
<td>5.2 ± 1.7</td>
</tr>
</tbody>
</table>

Values are means ± SD. * p<0.05, versus group with NBIH.
Table 4 shows the qualitative description results of training activities of the skaters. For females, there was a significant greater number of skaters with BIH who cooled-down after every session ($\chi^2=3.0$, df=1, $p<0.05$) and more skaters with BIH tended to warm-up before every session as well ($\chi^2=5.5$, df=1, $p=0.08$). There were no other significant differences for the female group. For males, there were no significant differences in any of the categories.

### Table 4. Qualitative Description of Training Activities

<table>
<thead>
<tr>
<th></th>
<th>Male BIH</th>
<th>Male NBIH</th>
<th>Female BIH</th>
<th>Female NBIH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm-up before every session</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Cool down after every session</td>
<td>80% (4/5)</td>
<td>75% (3/4)</td>
<td>86%* (6/7)</td>
<td>47% (8/17)</td>
</tr>
<tr>
<td>Know how many jumps they attempt a session</td>
<td>40% (2/5)</td>
<td>0% (0/4)</td>
<td>57%* (4/7)</td>
<td>12% (2/17)</td>
</tr>
<tr>
<td>Have a set jump maximum</td>
<td>0% (0/5)</td>
<td>0% (0/4)</td>
<td>0% (0/7)</td>
<td>0% (0/17)</td>
</tr>
<tr>
<td>Jumps/session</td>
<td>36.3 ± 1.3</td>
<td>**</td>
<td>25.0 ± 0.0</td>
<td>35.6 ± 4.5</td>
</tr>
<tr>
<td>Landing leg</td>
<td>Right, 100% (5/5)</td>
<td>Right, 75% (3/4)</td>
<td>Right, 100% (7/7)</td>
<td>Right, 78% (14/18)</td>
</tr>
</tbody>
</table>

Values are expressed as percentages except for jumps/session which is mean ± SD.
* $p<0.05$, versus group with NBIH.
** No males with NBIH knew the number of jumps attempted.

---

**Figure 14. Differences in Training patterns in the female skaters.** Female skaters with BIH warmed up and cooled-down more frequently than skaters with NBIH. * $p<0.05$, versus group with NBIH.
**Muscle Flexibility Assessment**

Table 5 shows aspects of overall core stability and strength parameters for skaters. In males, the group of men with BIH had significantly higher two foot vertical jump and landing leg vertical jump heights (p<0.05) and tended to also have higher free leg vertical jump (p=0.08). There were no other significant differences between the two male groups or between the free leg and landing leg. For the female groups, there were no significant differences between the two groups or within the groups.

**Table 5.** Overall Core Stability and Strength

<table>
<thead>
<tr>
<th></th>
<th>Male BIH</th>
<th>Male NBIH</th>
<th>Female BIH</th>
<th>Female NBIH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Push-ups completed</td>
<td>29.0 ± 6.6</td>
<td>21.0 ± 7.8</td>
<td>17.4 ± 6.9</td>
<td>13.6 ± 5.4</td>
</tr>
<tr>
<td>Time side plank held (sec)</td>
<td>54.6 ± 26.8</td>
<td>50.3 ± 31.2</td>
<td>77.4 ± 14.6</td>
<td>63.4 ± 30.9</td>
</tr>
<tr>
<td>Two foot jump (inches)</td>
<td>26.0 ± 2.6*</td>
<td>19.2 ± 2.5</td>
<td>19.1 ± 0.7</td>
<td>18.6 ± 2.4</td>
</tr>
<tr>
<td>Free leg jump (inches)</td>
<td>18.2 ± 2.5</td>
<td>13.4 ± 2.3</td>
<td>13.9 ± 1.1</td>
<td>12.8 ± 2.3</td>
</tr>
<tr>
<td>Landing leg jump (inches)</td>
<td>19.1 ± 2.9*</td>
<td>13.7 ± 1.2</td>
<td>13.8 ± 1.2</td>
<td>13.1 ± 1.9</td>
</tr>
</tbody>
</table>

Values are means ± SD. * p<0.05, versus group with NBIH.

**Figure 15. Differences in Jump Height in Male Skaters.** The men with BIH jumped significantly higher during their two foot vertical jumps and their landing leg vertical jumps while the free leg showed an increased trend as well. * p<0.05, versus group with NBIH.
Table 6 shows parameters for the ankle flexibility testing of skaters. There were no significant differences between the two groups of males. For the female groups, skaters with NBIH had a significantly increased degree of dorsiflexion in the FL and LL (p<0.05). There were no other significant differences seen.

Table 6. Ankle Flexibility of Skaters

<table>
<thead>
<tr>
<th>Ankle</th>
<th>Male BIH</th>
<th>Male NBIH</th>
<th>Female BIH</th>
<th>Female NBIH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plantar flexion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LL</td>
<td>32.0 ± 5.1</td>
<td>33.3 ± 8.5</td>
<td>36.4 ± 4.4</td>
<td>36.9 ± 5.8</td>
</tr>
<tr>
<td>FL</td>
<td>34.0 ± 5.8</td>
<td>35.0 ± 7.1</td>
<td>35.7 ± 4.9</td>
<td>36.4 ± 4.7</td>
</tr>
<tr>
<td>Dorsiflexion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LL</td>
<td>16.4 ± 7.1</td>
<td>18.3 ± 2.4</td>
<td>16.3 ± 1.7*</td>
<td>19.0 ± 4.1</td>
</tr>
<tr>
<td>FL</td>
<td>18.0 ± 6.8</td>
<td>16.7 ± 2.4</td>
<td>15.0 ± 2.7*</td>
<td>18.8 ± 3.3</td>
</tr>
</tbody>
</table>

Values are means ± SD. * p<0.05, versus group with NBIH.

Figure 16. Difference in ankle dorsiflexion between the female skaters. Females with NBIH had significantly greater degree of dorsiflexion than the females with BIH. * p<0.05, versus group with NBIH.
Table 7 shows the values for the flexibility of the hip and the upper leg of skaters. There were no significant differences seen for either males or females. Males with BIH tended to have more hip flexion flexibility (p=0.09 and p=0.17, FL and LL, respectively) and had less hip abduction flexibility (p=0.09 and p=0.17, FL and LL, respectively).

Table 7. Hip and Upper Leg Flexibility of Skaters

<table>
<thead>
<tr>
<th>Hip</th>
<th>Male BIH</th>
<th>Male NBIH</th>
<th>Female BIH</th>
<th>Female NBIH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion</td>
<td>96.4 ± 6.5</td>
<td>71.7 ± 17.0</td>
<td>106.7 ± 15.8</td>
<td>100.8 ± 7.3</td>
</tr>
<tr>
<td></td>
<td>102.0 ± 6.0</td>
<td>68.3 ± 16.5</td>
<td>104.0 ± 21.0</td>
<td>101.4 ± 7.8</td>
</tr>
<tr>
<td>Extension</td>
<td>13.8 ± 3.7</td>
<td>8.0 ± 5.0</td>
<td>10.7 ± 2.9</td>
<td>10.7 ± 3.6</td>
</tr>
<tr>
<td></td>
<td>13.6 ± 2.8</td>
<td>10.3 ± 6.8</td>
<td>9.8 ± 3.5</td>
<td>11.3 ± 4.6</td>
</tr>
<tr>
<td>Thomas test</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>LL 100% (5/5)</td>
<td>100% (3/3)</td>
<td>57.1%</td>
<td>64.7%</td>
</tr>
<tr>
<td></td>
<td>FL 80% (4/5)</td>
<td>100% (3/3)</td>
<td>57.1%</td>
<td>64.7%</td>
</tr>
<tr>
<td>Abduction</td>
<td>44.0 ± 8.0</td>
<td>51.7 ± 4.7</td>
<td>52.1 ± 6.3</td>
<td>52.2 ± 8.2</td>
</tr>
<tr>
<td></td>
<td>56.7 ± 4.7</td>
<td>52.9 ± 8.4</td>
<td>52.2 ± 9.2</td>
<td></td>
</tr>
<tr>
<td>Quadriceps</td>
<td>130.4 ± 9.2</td>
<td>136.7 ± 6.2</td>
<td>140.0 ± 5.3</td>
<td>137.5 ± 6.3</td>
</tr>
<tr>
<td></td>
<td>132.4 ± 8.4</td>
<td>136.7 ± 6.2</td>
<td>140.7 ± 7.8</td>
<td>138.9 ± 6.1</td>
</tr>
<tr>
<td>ITB/Ober Test</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>LL 80% (4/5)</td>
<td>66.7% (2/3)</td>
<td>85.7%</td>
<td>72.2%</td>
</tr>
<tr>
<td></td>
<td>FL 100% (5/5)</td>
<td>66.7% (2/3)</td>
<td>100%</td>
<td>66.7%</td>
</tr>
</tbody>
</table>

Values are expressed as means ± SD and as percentages for positive Thomas and ITB/Ober Tests.
Figure 17. Differences in Hip Flexibility of Male Skaters. The men with BIH showed greater flexibility during hip flexion but showed less during hip abduction.

Table 8 shows the values measured for upper body flexibility. No significant differences were found for shoulder internal rotation (IR) or arm abduction in the two groups of males or the two groups of females.

Table 8. Upper Body Flexibility of Skaters

<table>
<thead>
<tr>
<th></th>
<th>Male BIH</th>
<th>Male NBH</th>
<th>Female BIH</th>
<th>Female NBH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder IR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LL</td>
<td>133.0 ± 9.8</td>
<td>136.7 ± 12.4</td>
<td>124.3 ± 9.7</td>
<td>127.3 ± 12.1</td>
</tr>
<tr>
<td>FL</td>
<td>132.0 ± 12.9</td>
<td>131.7 ± 16.5</td>
<td>121.4 ± 13.0</td>
<td>128.6 ± 10.5</td>
</tr>
<tr>
<td>Arm abduction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LL</td>
<td>167.0 ± 26.0</td>
<td>180.0 ± 0.0</td>
<td>180.0 ± 0.0</td>
<td>179.2 ± 1.1</td>
</tr>
<tr>
<td>FL</td>
<td>170.0 ± 20.0</td>
<td>180.0 ± 0.0</td>
<td>180.0 ± 0.0</td>
<td>179.2 ± 1.1</td>
</tr>
</tbody>
</table>

Values are expressed as means ± SD.
Table 9 shows the values obtained during the squat analysis in both sneakers and skates. In sneakers, men with BIH had significantly (p<0.05) less flexion at the knees when compared to the men with NBIH. With skates on, the men with BIH had significantly less flexion at the knees and compared to the vertical than the men with NBIH. Both groups of men had significantly (p<0.05) less ankle flexion in their skates versus their sneakers. The men with BIH also had significantly (p<0.05) less knee flexion with their skates on versus sneakers. No other significant differences were seen between male groups or between sneakers and skates. For the females with BIH, there was significantly (p<0.05) less flexion in the ankles for sneakers versus skates and a trend (p=0.07) for less knee flexion. For the females with NBIH, there was significant (p<0.05) decreases in flexion at the hips, knees and ankles between sneakers and skates. There were no other significant differences.

<table>
<thead>
<tr>
<th>Test</th>
<th>Male BIH</th>
<th>Male NBIH</th>
<th>Female BIH</th>
<th>Female NBIH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hip flexion (°)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-sneakers</td>
<td>40.6 ± 11.3</td>
<td>34.1 ± 5.5</td>
<td>38.8 ± 5.1</td>
<td>44.2 ± 9.7</td>
</tr>
<tr>
<td><strong>Knee flexion (°)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-sneakers</td>
<td>50.7 ± 6.5**</td>
<td>33.0 ± 2.9</td>
<td>38.3 ± 14.0</td>
<td>47.2 ± 12.6</td>
</tr>
<tr>
<td><strong>Ankle flexion (°)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-sneakers</td>
<td>49.3 ± 1.9</td>
<td>52.3 ± 2.4</td>
<td>49.9 ± 6.3</td>
<td>47.8 ± 6.5</td>
</tr>
<tr>
<td><strong>Vertical angle (°)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-sneakers</td>
<td>50.0 ± 4.7</td>
<td>38.3 ± 9.1</td>
<td>35.2 ± 9.0</td>
<td>42.4 ± 10.2</td>
</tr>
<tr>
<td><strong>Hip flexion (°)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-skates</td>
<td>47.1 ± 20.6</td>
<td>36.2 ± 3.3</td>
<td>42.2 ± 12.0</td>
<td>52.2 ± 15.5*</td>
</tr>
<tr>
<td><strong>Knee flexion (°)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-skates</td>
<td>64.8 ± 12.3**</td>
<td>35.8 ± 3.9</td>
<td>51.7 ± 15.4</td>
<td>62.7 ± 16.1b</td>
</tr>
<tr>
<td><strong>Ankle flexion (°)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-skates</td>
<td>60.0 ± 2.0b</td>
<td>63.1 ± 3.6a</td>
<td>64.9 ± 6.2b</td>
<td>62.1 ± 4.7b</td>
</tr>
<tr>
<td><strong>Vertical angle (°)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-skates</td>
<td>48.8 ± 9.3*</td>
<td>32.4 ± 0.6</td>
<td>42.0 ± 5.7</td>
<td>43.3 ± 6.8</td>
</tr>
</tbody>
</table>

Values are means ± SD. * p<0.05, versus group with NBIH. ** p<0.01, vs. group with NBIH. a p<0.05, vs. group in sneakers. b p<0.01, vs. group in sneakers
Figure 18. Differences in Off-ice Biomechanics of Male Skaters. The males with BIH showed less knee flexion in both skates and sneakers and more flexion compared to the vertical with skates on. * p<0.05, versus group with NBIH.

Figure 19. Flexion Differences between Sneakers and Skates for Male and Female Skaters. Males with BIH showed significantly less knee flexion in skates versus sneakers. Females with NBIH had significantly less hip and knee flexion in skates versus sneakers. Females with BIH showed a trend of less knee flexion in skates versus sneakers. * p<0.05, versus skates.
**Muscle Strength Assessments**

Table 10 shows the values obtained during the testing of the hip strength of skaters. The men with BIH had significantly stronger hip abduction with the FL when compared to the men with NBIH (p<0.05). There were no other significant differences seen. For the female groups, there was a significant increase in strength for hip adduction on the LL versus the group with NBIH (p>0.05). No other significant differences were seen.

**Table 10. Hip Strength of Skaters**

<table>
<thead>
<tr>
<th></th>
<th>Male back injuries</th>
<th>Male non-back injuries</th>
<th>Female back injuries</th>
<th>Female non-back injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip adduction</td>
<td>LL 4.6 ± 0.5</td>
<td>4.3 ± 0.5</td>
<td>4.8 ± 0.4*</td>
<td>4.3 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>FL 4.7 ± 0.6</td>
<td>4.3 ± 0.5</td>
<td>4.7 ± 0.5</td>
<td>4.4 ± 0.5</td>
</tr>
<tr>
<td>Hip abduction</td>
<td>LL 4.7 ± 0.6</td>
<td>4.3 ± 0.5</td>
<td>4.9 ± 0.2</td>
<td>4.8 ± 0.3</td>
</tr>
<tr>
<td></td>
<td>FL  5.0 ± 0.0*</td>
<td>4.2 ± 0.2</td>
<td>4.9 ± 0.2</td>
<td>4.9 ± 0.4</td>
</tr>
<tr>
<td>Hip extension</td>
<td>LL 4.9 ± 0.2</td>
<td>4.7 ± 0.5</td>
<td>4.9 ± 0.4</td>
<td>4.8 ± 0.4</td>
</tr>
<tr>
<td></td>
<td>FL  5.0 ± 0.0</td>
<td>4.7 ± 0.5</td>
<td>4.8 ± 0.4</td>
<td>4.8 ± 0.3</td>
</tr>
</tbody>
</table>

Values are means ± SD. * p<0.05, versus group with NBIH.
Table 11 shows the values measured during the testing of ankle strength of skaters. No significant differences were seen between the two male groups. There was a significant (p<0.05) increase in ankle eversion strength on the FL of the female skaters with BIH. No other significant differences were seen in the two female groups.

Table 11. Ankle Strength of Skaters

<table>
<thead>
<tr>
<th>Ankle</th>
<th>Male BIH</th>
<th>Male NBIH</th>
<th>Female BIH</th>
<th>Female NBIH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plantar flexion</td>
<td>FL 5.0 ± 0.0</td>
<td>5.0 ± 0.0</td>
<td>5.0 ± 0.0</td>
<td>5.0 ± 0.0</td>
</tr>
<tr>
<td></td>
<td>LL 5.0 ± 0.0</td>
<td>5.0 ± 0.0</td>
<td>5.0 ± 0.0</td>
<td>5.0 ± 0.0</td>
</tr>
<tr>
<td>Dorsiflexion</td>
<td>FL 5.0 ± 0.0</td>
<td>4.8 ± 0.2</td>
<td>4.9 ± 0.2</td>
<td>4.9 ± 0.3</td>
</tr>
<tr>
<td></td>
<td>LL 5.0 ± 0.0</td>
<td>5.0 ± 0.0</td>
<td>5.0 ± 0.0</td>
<td>4.9 ± 0.3</td>
</tr>
<tr>
<td>Eversion</td>
<td>FL 4.5 ± 0.8</td>
<td>4.7 ± 0.5</td>
<td>4.9 ± 0.2*</td>
<td>4.6 ± 0.4</td>
</tr>
<tr>
<td></td>
<td>LL 4.7 ± 0.4</td>
<td>5.0 ± 0.0</td>
<td>4.7 ± 0.5</td>
<td>4.8 ± 0.3</td>
</tr>
<tr>
<td>Inversion</td>
<td>FL 4.7 ± 0.6</td>
<td>5.0 ± 0.0</td>
<td>4.6 ± 0.4</td>
<td>4.6 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>LL 4.6 ± 0.8</td>
<td>4.8 ± 0.2</td>
<td>4.7 ± 0.5</td>
<td>4.8 ± 0.4</td>
</tr>
</tbody>
</table>

Values are means ± SD. * p<0.05, versus group with NBIH.

Table 12 shows the values measured during the testing of the upper body strength of skaters. No significant differences were seen in upper body strength of the two male groups. For the female groups, there was a significant (p<0.05) increase in strength for the deltoids and on the FL side of the body for the supraspinatus muscle for the skaters with BIH vs. NBIH. There were no other significant differences seen.

Table 12. Upper Body Strength of Skaters

<table>
<thead>
<tr>
<th></th>
<th>Male BIH</th>
<th>Male NBIH</th>
<th>Female BIH</th>
<th>Female NBIH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deltoids</td>
<td>FL 4.8 ± 0.2</td>
<td>4.8 ± 0.2</td>
<td>5.0 ± 0.0*</td>
<td>4.8 ± 0.3</td>
</tr>
<tr>
<td></td>
<td>LL 4.9 ± 0.2</td>
<td>4.8 ± 0.2</td>
<td>5.0 ± 0.0**</td>
<td>4.8 ± 0.3</td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>FL 4.8 ± 0.4</td>
<td>5.0 ± 0.0</td>
<td>5.0 ± 0.0*</td>
<td>4.8 ± 0.3</td>
</tr>
<tr>
<td></td>
<td>LL 4.7 ± 0.4</td>
<td>5.0 ± 0.0</td>
<td>5.0 ± 0.0</td>
<td>4.9 ± 0.3</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>FL 4.6 ± 0.6</td>
<td>4.8 ± 0.2</td>
<td>4.6 ± 0.4</td>
<td>4.5 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>LL 4.6 ± 0.6</td>
<td>4.8 ± 0.2</td>
<td>4.5 ± 0.4</td>
<td>4.5 ± 0.4</td>
</tr>
<tr>
<td>Subscapularis</td>
<td>FL 4.6 ± 0.4</td>
<td>4.7 ± 0.5</td>
<td>4.2 ± 0.4</td>
<td>4.3 ± 0.4</td>
</tr>
<tr>
<td></td>
<td>LL 4.6 ± 0.4</td>
<td>4.3 ± 0.5</td>
<td>4.3 ± 0.5</td>
<td>4.2 ± 0.4</td>
</tr>
<tr>
<td>Serratusanterior</td>
<td>FL 5.0 ± 0.0</td>
<td>5.0 ± 0.0</td>
<td>4.9 ± 0.2</td>
<td>4.7 ± 0.4</td>
</tr>
<tr>
<td></td>
<td>LL 4.8 ± 0.4</td>
<td>5.0 ± 0.0</td>
<td>4.7 ± 0.4</td>
<td>4.7 ± 0.4</td>
</tr>
</tbody>
</table>

Values are means ± SD. * p<0.05, versus group with NBIH, ** p<0.01, vs. group with NBIH.
Table 13 shows the results for the abdominal strength test, the Kendal Double leg lowering assessment. Both male and female skaters with BIH showed trends of greater abdominal strength versus the groups with NBIH (p=0.16 for females, p=0.23 for males)

Table 13. Abdominal Strength of Skaters

<table>
<thead>
<tr>
<th>Abdominals</th>
<th>Male back injuries</th>
<th>Male non-back injuries</th>
<th>Female back injuries</th>
<th>Female non-back injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double leg lowering</td>
<td>34.8 ± 30.9</td>
<td>56.7 ± 2.4</td>
<td>36.9 ± 24.8</td>
<td>53.7 ± 14.7</td>
</tr>
<tr>
<td>(degrees)</td>
<td>(0-82)</td>
<td>(55-60)</td>
<td>(0-68)</td>
<td>(25-75)</td>
</tr>
</tbody>
</table>

Values are means ± SD (min-max).

On-ice jumping assessment

Table 14 shows the results of the on-ice jumping technique.

For the male groups, there was a significantly greater time spent in the air and a larger degree of flexion at the hip during landing for the males with BIH versus the males with NBIH (p<0.05). There were no other significant differences were seen in the landing position, except for increased degree of flexion at the knee (p=0.07). There was also a significant increase in the degree of flexion of the men with NBIH from the take-off to the landing position at the ankles and compared to the vertical (p<0.05).

For the female groups, there were no significant differences between groups but there was an upward trend for the landing position (p=0.1-0.18). There was a significant difference in the degree of flexion of the females with NBIH from the take-off to the landing position at the hips and compared to the vertical (p<0.05).
Table 14. On-ice Jumping Biomechanical Analysis

<table>
<thead>
<tr>
<th></th>
<th>Male BIH</th>
<th>Male NBIH</th>
<th>Female BIH</th>
<th>Female NBIH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take-off leg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-vertical (θ)</td>
<td>34.5 ± 9.8</td>
<td>27.1 ± 9.8</td>
<td>33.1 ± 8.4</td>
<td>32.7 ± 10.0</td>
</tr>
<tr>
<td>-hip (θ)</td>
<td>87.9 ± 22.7</td>
<td>98.5 ± 20.1</td>
<td>94.5 ± 14.9</td>
<td>96.6 ± 19.6</td>
</tr>
<tr>
<td>-knee (θ)</td>
<td>88.7 ± 13.3</td>
<td>95.7 ± 12.2</td>
<td>94.7 ± 10.2</td>
<td>95.1 ± 9.8</td>
</tr>
<tr>
<td>-ankle (θ)</td>
<td>59.2 ± 7.4</td>
<td>60.6 ± 6.1</td>
<td>59.3 ± 11.4</td>
<td>60.1 ± 10.6</td>
</tr>
<tr>
<td>Landing leg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-vertical (θ)</td>
<td>39.0 ± 9.9</td>
<td>35.2 ± 10.6a</td>
<td>34.3 ± 8.6</td>
<td>39.3 ± 9.7b</td>
</tr>
<tr>
<td>-hip (θ)</td>
<td>82.2 ± 8.8**</td>
<td>103.1 ± 15.7</td>
<td>90.1 ± 10.7</td>
<td>84.5 ± 13.6b</td>
</tr>
<tr>
<td>-knee (θ)</td>
<td>84.1 ± 11.4</td>
<td>95.5 ± 12.8</td>
<td>97.0 ± 9.6</td>
<td>92.0 ± 13.4</td>
</tr>
<tr>
<td>-ankle (θ)</td>
<td>57.8 ± 9.2</td>
<td>51.3 ± 8.7b</td>
<td>64.8 ± 9.3</td>
<td>60.2 ± 9.5</td>
</tr>
<tr>
<td>Body Angle</td>
<td>10.6 ± 4.9</td>
<td>8.8 ± 3.6</td>
<td>10.7 ± 4.9</td>
<td>10.1 ± 5.2</td>
</tr>
<tr>
<td>compared to</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>vertical in air</td>
<td>0.57 ± 0.06**</td>
<td>0.50 ± 0.03</td>
<td>0.47 ± 0.05</td>
<td>0.46 ± 0.06</td>
</tr>
<tr>
<td>Time in air (s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values are means ± SD. * p<0.05, versus group with NBIH., ** p<0.01, vs. group with NBIH, a p<0.05, vs. take-off position, b p<0.01, vs. take-off position

Figure 20. Differences in Male Skater Landing Positions. The males with NBIH showed significantly less hip flexion during their landing positions. * p<0.05, versus group with NBIH.
Figure 21. Differences in Take-off vs. Landing Positions in Skaters. The males with NBIH showed significantly different ankle flexion and vertical angles from the take-off to landing positions. The females with NBIH showed significantly different hip flexion and vertical angle from the take-off to landing positions. * p<0.05, versus landing position.
DISCUSSION

The goal of this study was to compare the on and off ice training patterns and movements of skaters with repeated injuries to those who are uninjured. By comparing these two groups, we expect to find specific imbalances in muscle strength and flexibility and/or different hours of training that might be leading to injuries. By incorporating biomechanical data in skates on and off the ice, we hope to create more accurate data for establishing differences between the two groups of skaters. We anticipate that this data may lead to more age-appropriate training regimens for skaters and promote safer training and skill growth while lowering the incidence of injuries.

In this study, 34 skaters agreed to participate. 12 skaters were assigned to the group with back injury history (BIH) and 22 skaters were assigned to the group with no back injury history (NBIH). Skaters were stratified into male and female groups to ensure any differences between sexes would not skew the data. Although there were not as many significant differences as expected, a few significant differences were discovered along with trends that might indicate why certain skaters ended up in a particular group. From the results, it is clear there are gender-specific reasons which separate certain skaters into the category of BIH or NBIH.

An important concept to remember in this study was that we were looking at retrospective injury data. Even when a skater was placed in the BIH group, it did not necessarily mean they were experiencing back pain at the time of testing. We need to take into account that the skaters with BIH may have recognized that they were having injury problems and do in fact have better training techniques than their counterparts with NBIH. This would imply that the skaters with NBIH could be more susceptible to injury as they have not yet experienced the same setbacks as the skaters with BIH.
Differences between the two groups might be the cause of the past injuries, a result from the past injuries or co-incidental findings.

For the male group of skaters, the men with BIH had skated significantly (p<0.05) more years than the group with NBIH. Consistent with this finding, the men with BIH were older (p=0.11) and the mode skating level for males with BIH was the senior level while for the males with NBIH it was the novice level. As one would expect from older and more experienced skaters, the group of men with BIH had significantly (p<0.05) higher two-foot vertical jump and landing leg vertical jump heights and tended (p=0.08) to also have higher free leg (FL) vertical jump. This group also performed more (p<0.05) hours of off-ice training and total hours of training per week compared to the men with NBIH. There were no differences in the number of males with BIH or NBIH that warmed-up or cooled-down before and after each session. This pattern indicates that the men with BIH are overall stronger and are performing more physical training than the men with NBIH.

Similar to the male counterparts, the females with BIH were also older and had skated for more years (p=0.11 and p=0.15, respectively). The females with BIH did significantly (p<0.05) more hours of off-ice training, warming-up and overall training time. There was a significant (p<0.05) greater number of female skaters with BIH who cooled-down after every session and more female skaters with BIH warmed-up before every session as well (p=0.08). This is the first sign that the females with BIH are training better than the NBIH group.

Push-ups are important tools for overall strength analysis. The push-up has been considered the ultimate barometer of fitness since it tests the entire body by engaging muscle groups in the arms, chest, abdomen, hips and legs (Parker-Pope,
2008). They are also considered to be indicators of muscle endurance. For both males and females, the difference between the groups in number of push-ups was not significant. There were also not many differences seen for upper body strength. The male groups showed no differences for any of the upper body strength tests despite having two pair skaters in the BIH group and one pair skater in the NBIH group. For the female groups, there was a significant (p<0.05) increase in strength for the deltoids and on the supraspinatus muscle on the FL side of the body for the skaters with BIH versus NBIH. This may be a co-incidental finding but may also have occurred because this group has developed better training techniques and are an older and stronger group.

In order to measure core strength, side planks and the Kendall Abdominal Test were used. Side planks have been described as an exercise that challenges the lateral stabilizers, particularly the quadratus lumborum muscle groups (McGill et al, 1999). In our study, the male groups showed no significant difference in side plank time held while the females with BIH showed a trend (p=0.15) of holding it longer than their counterparts in the NBIH group. This is opposite to the finding by Leetun et al (2004) who reported that uninjured basketball and track athletes held the side planks longer than a group with injury history. The Kendall Double Leg Lowering Abdominal Test is indicative of rectus abdominus and external obliques strength. A study by Krause et al (2005) concluded that people with back problems may show lack of ability to perform the exercise. However, in the present study, the skaters with BIH did not show this inability as both males and females were able to perform it well. The male groups in this study showed no significant differences between degrees of lowering their legs. The female group with BIH showed a trend (p=0.16) of being able to lower their legs more (indicative of stronger abdominals). This is another sign that the females with BIH are actually
stronger overall and may therefore be less vulnerable to another injury. Lanning et al, (2006) showed an average of 50 degrees of lowering for collegiate athletes aged 19.2 in a variety of sports. The skaters with BIH in this study had values of 34.8 and 36.9 (males and females, respectively) while the skaters with NBIH had values of 53.7 and 56.7 (males and females, respectively). The skaters with BIH therefore had greater strength than average collegiate athletes while the group with NBIH showed similar strength. Therefore, in terms of rectus abdominis strength, it would appear the two groups of BIH are not vulnerable in that category.

There were not as many strength differences as expected. The men with BIH had significantly (p<0.05) stronger hip abduction with the FL when compared to the men with NBIH. This finding might reflect the need for more strength for the landing of bigger and more difficult jumps. This difference in strength may have developed as compensation on landing positions attempting to keep the body stable and in control. For the female groups, there was a significant (p<0.05) increase in strength for hip adduction on the LL versus the group with NBIH. This strength in the landing leg (LL) might be important in order to keep the skaters in line during landing and balance the momentum and abductor muscles during landing. There was also a significant increase in ankle eversion strength on the FL of the female skaters with BIH (p<0.05). This may be due to the many years of training and trying to turn the toe out with plantar flexion to look aesthetically pleasing.

Flexibility is also a very important aspect in preventing injuries and maintaining a healthy body. Sports-specific stretching programs have been suggested to help promote maximum performance and help prevent flexibility-related injuries (Chandler et al., 1990). Parkin et al (2001) reported asymmetries in the erector spinae muscles of
oarsmen correlating with their dominant side and related this to the high incidence of lower back pain. Hides et al (2008) also found asymmetries in muscle size on the dominant leg versus the opposite leg of football league players but did not feel this asymmetry was related to the number of injuries. Therefore, although we did find asymmetries in skaters, this may not be the only underlying cause of injuries. This information does indicate that it is important to compare the landing leg of skaters versus their free leg (as compared to solely the left and right side of the body).

Differences in flexibility between the two groups were not as apparent as we expected. No upper body flexibility issues were seen. For females, the only lower body flexibility difference was that the skaters with NBIH had a significantly increased degree of dorsiflexion in the FL and LL (p<0.05). This might be important on the LL for landing jumps but may be a co-incidental finding for the FL. Males with BIH tended to have more hip flexion flexibility (p=0.09 and p=0.17, FL and LL, respectively) and had less hip abduction flexibility (p=0.09 and p=0.17, FL and LL, respectively). These findings might be compensatory from the years of jumping and landing and the need to find ways to stay upright.

The major objective of the present study was to evaluate the biomechanics of skaters on and off the ice. By integrating these two settings, we hoped to obtain specific insights into the possible contributing factors to injuries. Again, one has to keep in mind that the differences we noticed can be either contributing to an injury or can be the consequence of an injury. To my knowledge, very few studies have evaluated these aspects on a quantitative level.

The off-ice squat analysis showed several unique differences between male skaters with NBIH and those with BIH. In both sneakers and skates, the men with BIH
had significantly (p<0.01) less flexion at the knees when compared to the men with NBIH. Along with this finding, the men with BIH had significantly (p<0.05) less knee flexion when comparing their movements in skates versus in sneakers. In addition, this group had a greater angle bent forward compared to the upright position than the men with NBIH (p<0.05). Considering that the men with BIH had less knee flexion both in sneakers and in skates, they appear to be unable to get deep into their knees during a static, isometric movement, irrespective of their footwear. A concerning finding is that the knee flexion is much less in skates than in sneakers. If they struggle while standing still off the ice, movement during a jump on the ice might be even harder to control and these skaters may need to compensate more with other muscle groups throughout the jump. This finding indicates that although the skaters are relatively quite strong, there seems to be a lack of coordination between using this strength and performing intricate, controlled movements. This may reflect a lack of neuromuscular control and might be a reason for why these skaters have had injuries in the past.

Along with the lack of knee flexion, the greater angle compared to the upright position indicates that these men are bending forwards, or breaking at the hips more and therefore are either not using their core or back extensor muscles appropriately. Although the Kendall Abdominal Test and the hip extension strength test showed no differences between the two groups, one might assume that other aspects of trunk core and stability are causing the men with BIH to have such poor motions. Both groups of men also had significantly less ankle flexion in their skates versus their sneakers (p<0.05). This is expected because the stiffness of figure skates does not allow for very much ankle flexion. A study by Haguenauer et al (2006) reported that in healthy skaters performing a vertical jump with skates on versus sneakers, the ankle and knee angular
amplitudes were limited significantly while wearing skates but the hip joint was not affected. This is similar to our findings in men with NBIH whereas in men with BIH the knee joint and the hip joint (indicated by the bending forwards) were affected by wearing skates. This difference raises the question as to whether it is the skates that are affecting skaters’ movement patterns or if there are neuromuscular insufficiencies that are causing this inability to control their motions.

Several other differences became apparent during the on ice analysis. The men with BIH spent significantly (p<0.01) greater time in the air. This is not surprising because this group was older, had skated longer and had greater vertical jumps off the ice. During the take-off, the men with BIH showed a trend (p=0.13) of greater flexion compared to the upright position versus the men with NBIH. Similar results were seen on the landing position as there was significantly (p<0.01) greater hip flexion for the men with BIH. Therefore, the males with BIH are struggling to stay upright during their take-off and landing positions. This bending at the hips is similar to what was seen during the off-ice analysis and might be further indicative of overall weak abdominal/back extensor muscles. The lack of postural control and dynamic stability contrasts with the finding that they are very strong overall and indicates that there might be neuromuscular and postural control problems in this group.

One opposite finding between the on and off ice analysis was that the men with BIH showed a trend (p=0.07) of greater flexion at the knees as compared to the men with NBIH during their landing positions. However, the ankle flexion for the males with NBIH tended (p=0.13) to be better than the males with BIH indicating they are using their ankles much more to absorb the impact of landing. One may hypothesize that the men with BIH have greater knee flexion because it might be the only way to save their jump
landings. By flexing so much at the hips, leaning forwards and not using their ankles, they must bend their knees more in order to have some type of landing edge. This motion repeated day after day may be a major factor that contributed to their back injuries in the first place. Moreover, even though they are stronger, by continuing these habits and setting no jump maximums for themselves, these skaters might be prone for more injuries in the future. One may therefore conclude that the men with BIH appear to be overall stronger, but unfortunately are potentially more vulnerable to injury due to their lack of mechanics when performing jumps on the ice. This on-ice analysis along with the off-ice results contributes to the conclusion that this group might be stronger but their mechanics may be pre-disposing them to further injury, possible due to lack of postural or neuromuscular stability. Although some interesting findings are apparent in this study, the small sample is a clear limitation and our findings need to be validated with a larger group of male skaters.

A similar analysis can also be done for the two female groups. During the squat analysis, the females with BIH had significantly (p<0.01) less flexion in their ankles for sneakers versus skates and a similar trend (p=0.07) for knee flexion. The lack of ankle flexion was again, expected and the lack of knee flexion indicates a similar result to the men that they were unable to compensate with their knees and shifted their motion to the hips and back. Their motion compared to the vertical also showed a trend (p=0.14) of increased forward flexion with skates on. Unfortunately for the females with NBIH, they showed significant (p<0.01) decreases in flexion at the knees and ankles while in skates versus in sneakers. Again, the ankle flexion is expected because of the equipment but the lack of flexion in the knees indicates that this group might also be vulnerable to back injuries because of the compensation at the hips and back. A
positive finding for this group was that although they had a significant \((p<0.05)\) increase in hip flexion in their skates, the lack of change in the vertical angle shows that this group might be trying to stand more upright while in skates rather than bending at the hips and compromising their body.

However, when comparing these groups, different results appear. In sneakers, the females with BIH showed less angle compared to the upright position \((p=0.13)\) and less flexion at the hips \((p=0.10)\) versus the females with NBIH. In skates, they had more knee flexion and less hip flexion \((p=0.17\) and \(p=0.13\), respectively). This indicates that although the group with BIH might have back pain from their lack of mobility in skates, the skaters with NBIH are actually more vulnerable because their positions are more mis-aligned.

Similar conclusions can be made from the on-ice jumping of the two female groups. No significant differences were seen during the take-off positions of the two female groups. During the landing position, the females with BIH showed trends \((p=0.16\) and \(p=0.18\), respectively) of greater ankle and knee flexion compared to the females with NBIH. As well, the females with BIH tended \((p=0.16)\) to show less hip flexion while the females with NBIH showed a trend \((p=0.11)\) of a greater angle forward compared to the vertical. This further supports the conclusion that the female skaters with NBIH are more vulnerable because they are not landing their jumps as well as the females with BIH and are thus at greater risk of back injuries. The females with NBIH also showed significantly \((p<0.01)\) greater vertical angle during their landing, significantly \((p<0.01)\) less of a hip angle indicating more forward movement and showed a trend \((p=0.20)\) of less knee flexion while no change in ankle bend as compared to their take-off. This
indicates that the females with NBIH are not strong enough overall and are compensating during their landing positions.

In conclusion, our findings indicate that the men with BIH are potentially more vulnerable to further injuries. Despite training many hours per week and being overall quite strong, their bodies do not have the control necessary to perform slow static movements or intense, reflex-like landings on the ice. Their dynamic stability and control is much more the problem than their strength. Working out is essential, but other aspects of their overall fitness must be addressed in order to truly meet their potential. Similar findings of dysfunctional biomechanics were found in the females with NBIH. This may make them prone to injuries in the future. From a prevention standpoint, identification of these dysfunctional movement patterns could lead to improved technique and/or training to lessen the risk of injury. Future studies into other aspects of skating such as spins, lifts and footwork, might indicate further patterns that are leading skaters to such vulnerabilities.
APPENDIX A

Introductory Letter For Coaches Letter
Dear __________.

In the next few weeks, Dr. Ellen Geminiani of Boston Children’s Hospital and David Leenen of Boston University will be starting a research study at The Skating Club of Boston on the possible connection between training patterns and back injuries among competitive figure skaters. Through a review of available SCOB records, you currently coach skaters who may qualify for our study. We are sure you can appreciate the importance of this type of research and seek your support in encouraging your skaters to participate. This study is completely voluntary.

In order to collect the most consistent data, we have established criteria for inclusion in the study. Skaters participating in this study must have competed at regionals, sectionals or nationals this 2013 competitive season and train at The Skating Club of Boston. This will allow us to evaluate a group of skaters training many hours a week and thus have a higher likelihood of injury.

The study consists of three different evaluations. First is a survey regarding training habits on and off the ice. Some of the questions include: how many years have you been skating? What is your current competition level? What is included in your warm up before each session? Although our research is primarily focused on back injuries, we will be collecting information on all injuries sustained by the skaters as part of a complete evaluation. The second section will assess flexibility and strength of various muscle groups. These evaluations will be conducted in the training room at The Skating Club of Boston and involve standard physical examinations with some tests completed wearing skates to more closely simulating what occurs on the ice. The third section will involve filming the skaters performing 3 separate jumps for a video biomechanical evaluation. We have chosen the axel, the loop and the lutz jump. We will be analyzing take-off and landing angles as well as alignment and additional movements through the jump.
All the data will then be analyzed to assess if any strength, flexibility or biomechanical patterns are correlated with back injuries. Each skater will receive his/her individual results as well as the aggregate results. If you would like to discuss the results with the research team and your skater, we would be happy to meet and evaluate the results with you.

Of course we can not predict the outcome of the study but we are hopeful it will perhaps answer some questions and raise new ones to direct future research. We deeply appreciate your involvement and help in this effort to improve our sport and keep the skaters healthy. Thank you and we look forward to working together.

If you have any questions please feel free to contact us.

Sincerely,

________________________
David Leenen, B.Sc.,M.A. cand
617-756-3395

________________________
Ellen Geminiani, M.D.
617-355-3501

________________________
Doug Zeghibe
Executive Director, The Skating Club of Boston
APPENDIX B

Consent/Assent Form
Protocol Title: The prevalence of back injuries amongst figure skaters in relation to their functional movement

Principal Investigator: Ellen Geminiani, MD

Why is this research study being conducted? What is its purpose?
Figure skating involves the entire body and consists of a lot of unilateral repetitive twisting and turning motions. These movements can cause skaters to develop asymmetries in muscle strength and this imbalance can lead to skaters being more vulnerable to injuries.

We would like to determine if a skaters’ functional mobility in terms of muscle strength and flexibility along with jump technique affects the likelihood of getting a back injury and/or affecting their performance. We hope to look at the different muscle groups involved (back extensors, abdominals, hip flexors) to see where specific flexibility and strength issues can be causing injury problems. This information will be used for research.

Who is conducting this research study, and where is it being conducted?
Dr. Ellen Geminiani, MD of Boston Children’s Hospital Division of Sports Medicine will be conducting the research. All research will be conducted at the Skating Club of Boston.

How are individuals selected for this research study? How many will participate?
We plan to enroll 65 patients for this study. Competitive figure skaters (singles and pairs), training 10+ hours a week at the Skating Club of Boston, and male and female ages 10-25 will be eligible for this study. Skaters with and without history of back pain are included. You/your child were identified as a potential research participant because you meet the above criteria as a member of the Skating Club of Boston.

What do I have to do if I am in this research study?
This study includes 3 parts. The first part of the study involves a questionnaire asking you/your child about basic skating information, training habits and injury history. The second part involves testing you/your child using muscle strength and flexibility tests off the ice in sneakers and in skates. The third part will be a video biomechanical analysis of on-ice jumping technique with three different jumps. The jumps you/your child perform will be the axel, the loop and the lutz jump.

The questionnaire asks basic skating information, training habits and injury history. It will take 10-15 minutes to complete. This is a one time questionnaire.

The biomechanical and physical assessment screening will measure your/your child’s strength and flexibility. This will look at where certain muscle groups are weak and/or asymmetry exists therefore exposing an individual to vulnerable areas of their body. You/your will be tested off the ice in sneakers and in skates. It will take 20-25 minutes to complete with clinicians and researchers administering it. This is a one time screening.

On-ice analysis: Video biomechanical analysis of on-ice jumping technique with three different jumps. You/your child will perform each of the 3 jumps (axel, the loop and the lutz jump) 1 time each in order to
confirm your technique. Clinicians will review and analyze the film and record the results on our video analysis form. This is a one-time filming.

**What are the risks of this research study? What could go wrong?**
There is a potential risk of breach of privacy, but this is minimal as you will have a unique ID and any identifiable data (including video) will be stored on a locked/encrypted computer. Private assessment will be made available upon request. Patient health data will be collected by BCH staff and hospital approved non-BCH staff participating in this study.

Skating involves a certain level of risk for you/your child. As a competitive skater, you/your child may have already suffered injuries as a result of skating. We will only ask you/your child to do jumps that you/your child are already familiar with (axel, the loop and the lutz jump) but jumping may result in risks, including but not limited to:
- Muscle strain and sprain
- And, potentially even in an extreme instance, a broken bone.

If you/your child are injured, we will stop the test and you/your child will be seen by the healthcare personnel at Skating Club of Boston and we will report and document all injuries according the Skating Club’s standard of care. If necessary, you/your child will be referred to the BCH Sports Medicine Clinic for treatment. You will have the same standard of care treatments all patients receive. If you suffer an injury the study will be stopped and you will not participate further.

The biomechanical and physical assessment involves [stretching and movement] that may result in [muscle strain or pulled muscles]. Again, if you/your child are injured, we will stop the test and you will receive attention for the healthcare personnel at the Skating Club.

**What are the benefits of this research study?**
There are several benefits to not only you/your child but also to future skaters. Having such a detailed, sports- specific analysis being performed, we might be able to pinpoint any weak areas of your body that might make you vulnerable to an injury. This analysis will also be useful for helping promote better overall strength and conditioning for future skaters. If a pattern is seen amongst current skaters, training of future athletes can focus more on these areas in order to lower injury rates in the future.

**Are there costs associated with this research study? Will I receive any payments?**
There will be no costs to you/your child for your participation in this research study.

**If I do not want to take part in this research study, what are the other choices?**
Participation in the study is voluntary. Refusing to participate will not interfere with current or future care received at Boston Children’s Hospital.

**What are my rights as a research participant?**
Participation in the study is voluntary. Refusing to participate in the study nor withdrawal will not interfere with current or future care received at Boston Children’s Hospital. If you no longer want to participate, you can withdraw your consent at any time by contacting research staff in person or by phone at 617-355-2635.

You may request results of this study by contacting David Leenen (617-756-3395).

**Why would I be taken off the study early?**
If you/your child are not able to participate in any of the three parts of the study (questionnaire, Biomechanical and Physical Assessment, or the video analysis) due to injury or absence you/your child may be removed from the study. You/your child may also withdraw from the study at any time you wish.
Other information that may help you
Boston Children’s Hospital has recently developed a web-based, interactive educational program for parents called “A Parent’s Guide to Medical Research.” To find out more about research at Children’s Hospital, please visit the program at www.researchchildrens.org.

Boston Children’s Hospital is interested in hearing your comments, answering your questions and responding to any concerns regarding clinical research at Children's Hospital. If you would like further information about the type of clinical research performed at the hospital or have suggestions, questions or concerns regarding clinical research you may send an email to cci@childrens.harvard.edu or call 617 355-7052 between the hours of 8:30 and 5:00.

Who may see, use or share your health information?
A copy of this consent form will not be placed in you/your child’s medical record.

The results of the tests performed for research purposes will not be placed in your/your child’s medical record. In this manner it will be unlikely that others within the hospital, an insurance company or employer would ever learn of such results.

You/your child’s health information is protected by a law called the Health Information Portability and Accountability act (HIPAA). In general, anyone who is involved in this research including those funding and regulating the study may see the data, including information about you. For example, the following people might see information about you:

- Research staff at Boston Children’s Hospital involved in this study
- Medical staff at Boston Children’s Hospital directly involved in your care that is related to the research or arises from it.
- Other researchers and centers that are a part of this study, including people who oversee research at that hospital.
- People at Boston Children’s Hospital who oversee, advise, and evaluate research and care. This includes the ethics board and quality improvement program.
- People from agencies and organizations that provide accreditation and oversight of research.
- People that oversee the study information such as data safety monitoring boards, clinical research organizations, data coordinating centers, and others.
- Sponsors or others who fund the research, including the government or private sponsors.
- Companies that manufacture drugs or devices used in this research.
- Federal and state agencies that oversee or review research information, such as the Food and Drug Administration, the Department of Health and Human Services, the National Institutes of Health, and public health and safety authorities.
- People or groups that are hired to provide services related to this research or research at Boston Children’s Hospital, including services providers, such as laboratories, and others.
- Your health insurer for portions of the research and related care that are considered billable.

If some law or court requires us to share the information, we would have to follow that law or final ruling.

Some people or groups who get your health information might not have to follow the same privacy rules. Once your information is shared outside of Boston Children’s Hospital, we cannot promise that it will remain private. If you/your child decide to share private information with anyone not involved in the study, the federal law designed to protect privacy may no longer apply to this information. Other laws may or may not protect sharing of private health information. If you have a question about this you may contact the Boston Children’s Hospital Privacy Office at 857-218-4680 which is set up to help you understand privacy and confidentiality.
Because research is ongoing we cannot give you an exact time when we will destroy this information. Researchers continue to use data for many years so it is not possible to know when they will be done.

We will also create a code for the research information we collect about you so identifying information will not remain with the data and will be kept separately. The results of this research may be published in a medical book or journal or be used for teaching purposes. However your name or identifying information will not be used without your specific permission.

**Your privacy rights**
If you or your child do not want to participate in this study, you do not have to. If you do want to participate, however, you must sign this form.

If you do not sign this form, it will not affect your care or your child’s care at Boston Children’s Hospital now or in the future and there will be no penalty or loss of benefits. You/your child can withdraw from the study and end your permission for Boston Children’s Hospital to use or share the protected information that was collected as part of the research, however you cannot get back information that was already shared with others. Once you remove your permission, no more private health information will be collected. If you wish to withdraw your health information will need to do so in writing.

You/your child may have the right to get some the information that was shared with others for research, treatment or payment. This information is available after the study analysis is done. To request the information, please contact the Hospital’s Privacy Officer at 857-218-4680.

**Contact Information**
I understand that I may use the following contact information to reach the appropriate person/office to address any questions or concerns I may have about this study. I know:

<table>
<thead>
<tr>
<th>I can call…</th>
<th>At</th>
<th>If I have questions or concerns about</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigator:</td>
<td>Phone: 617-355-3501</td>
<td>• General questions about the study</td>
</tr>
<tr>
<td>Ellen Geminiani, M.D.</td>
<td></td>
<td>• Research-related injuries or emergencies</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Any research-related concerns or complaints</td>
</tr>
<tr>
<td>Study Contact:</td>
<td>Phone: 617-756-3395</td>
<td>• General questions about the study</td>
</tr>
<tr>
<td>David Leenen</td>
<td>617-355-2635</td>
<td>• Research-related injuries or emergencies</td>
</tr>
<tr>
<td>Robbie MacDougall</td>
<td></td>
<td>• Any research-related concerns or complaints</td>
</tr>
<tr>
<td>Office of</td>
<td>Phone: 617-355-7052</td>
<td>• Rights of a research subject</td>
</tr>
<tr>
<td>Clinical</td>
<td></td>
<td>• Use of protected health information.</td>
</tr>
<tr>
<td>Investigations</td>
<td></td>
<td>• Compensation in event of research-related injury</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Any research-related concerns or complaints.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• If investigator/study contact cannot be reached.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• If I want to speak with someone other than the Investigator, Study Contact or research staff.</td>
</tr>
</tbody>
</table>
Documentation of Informed Consent and Authorization

- I have read this consent form and was given enough time to consider the decision to participate in this study.
- This research study has been satisfactorily explained to me, including possible risks and benefits.
- All my questions were satisfactorily answered.
- I understand that participation in this research study is voluntary and that I can withdraw at any time.
- I am signing this consent form prior to participation in any research activities.
- I give permission for my/my child’s participation in this research study and for the use of associated protected health information as described above (HIPAA).

Parent/Legal Guardian Permission (if applicable)
If the child to be involved in this research study is a foster child or a ward of the state please notify the researcher or their staff who is obtaining your consent.

- Date (MM/DD/YEAR)  Signature of Parent #1 or Legal Guardian  Relationship to child
- Date (MM/DD/YEAR)  Signature of Parent #2  (if required)  Relationship to child

☐ CHECK if 2nd parent signature not obtained above. The PI must document in research records, the reason and/or all attempts made before concluding 2nd parent was not ‘reasonably available’.

Child Assent (if applicable)

- Date (MM/DD/YEAR)  Signature of Child/Adolescent Subject

☐ If child/adolescent’s assent is not obtained above, please indicate reason below (check one):
  □ Assent is documented on a separate IRB-approved assent form
  □ Child is too young
  □ Other reason (e.g. sedated), please specify: ____________________________________________

Adult Subject (if applicable)

- Date (MM/DD/YEAR)  Signature of Adult Subject (18+ years)
ADULT SUBJECT - if decisionally impaired (if applicable)

Legal Authorized Representative/Guardian
I give permission for the person I am authorized to represent to participate in this research study and for the use of associated protected health information as described above (HIPAA).

- Date (MM/DD/YEAR)  Signature of Legal Guardian  Print Name

- Relationship to Subject * (This order must be followed. If there is a court appointed guardian, this is who needs to provide consent. If not, a health care proxy, followed by durable power of attorney and lastly, family members)
  - Court-Appointed Guardian
  - Health Care Proxy (Attach Proxy and ensure there is express authority to make health care decisions inclusive of research.)
  - Durable Power of Attorney (POA) (Durable POA may be limited to specific areas. Attach Durable POA and ensure it covers research.)
  - Family Member/Next of Kin, (in order of preference: spouses, parents and adult children)
    Specify relationship

Adult Assent (if applicable)
- Date (MM/DD/YEAR)  Signature of Adult Subject

- CHECK if Adult Subject’s assent not obtained above, and specify reason below:

Investigator or Associate’s Statement & Signature
- I have fully explained the research study described above, including the possible risks and benefits, to all involved parties (subject/parents/legal guardian as applicable).
- I have answered and will answer all questions to the best of my ability.
- I will inform all involved parties of any changes (if applicable) to the research procedures or the risks and benefits during or after the course of the study.
- I have provided a copy of the consent form sign by the subject/parent/guardian and a copy of the hospital’s privacy notification (if requested)

- Date (MM/DD/YEAR)  Signature of Investigator or Associate

Witness Statement & Signature
Required ONLY IF (check which one applies):
  - Consent document needs to be read to subject or legal representative, or
  - Communication impairments limit the subject’s ability to clearly express consent, or
  - Other reason: please specify

I confirm that the information in this consent form was accurately explained to, and understood by the subject, parent and/or legally authorized representative as required, and that informed consent was given freely.

- Date (MM/DD/YEAR)  Signature of Witness
APPENDIX C

Flyer
Interested in seeing if the left side of your body is as strong as the right side?

If you are 10-25 years old and competed at the 2013 regionals, sectionals or nationals, you may be eligible to participate in a research study. We hope to look at skaters’ muscle strength and flexibility to look for imbalances that may lead to injuries, specifically back injuries. Participants will:

- Complete a questionnaire discussing training patterns and injury history
- Undergo off-ice testing including a muscle flexibility and strength assessment
- Have three jumps videotaped to be analyzed for extra movements that might lead to higher chance of injury

This is a one time study and will include only 30 minutes of testing. Ellen Geminiani, MD of Boston Children’s Hospital will be conducting this study

All sections will be conducted at the Skating Club of Boston

For more information please contact
David Leenen at 617-756-3395,

dleenen@bu.edu

Or

Robbie MacDougall at 617-355-2635,

robert.macdougall2@childrens.harvard.edu
APPENDIX D

Questionnaire
Questionnaire

Age: _______
Landing leg:
□ Left □ Right

Number of years skating: _____
Current Level and Event(s): __________
Number of hours on-ice training per week: _____
Number of hours off-ice training per week: _____
Please describe your off-ice training activities:

Number of hours warming-up per week: _____
Do you warm up before every session?:
□ Yes □ No

Do you cool down after every session?:
□ Yes □ No

Please describe your warm-up and cool down activities:

Do you know how many jumps you perform per session?:
□ Yes □ No

If yes, how many? _____
Do you have a set maximum? _____
How often do you stretch per week? _______

Which muscles do you stretch?______________________________

How many competitions do you do per year: _______
Do you do any other sports/dance?:
□ Yes □ No

If yes, (please specify/how many hours per week)?
________________________________________
Have you ever had a back injury?

☐ Yes  ☐ No

If yes,

When was the first time (year): _____
What was the cause: _____________
How often: ______

Was it a sudden or gradual onset?:
☐ Sudden  ☐ Gradual onset

Where was the injury on your back?
☐ Upper  ☐ Middle  ☐ Lower

Was it your left side, right side or both?:
☐ Left  ☐ Right  ☐ Both

Please describe the pain (sharp/dull/tight/cramp/etc.): _________________

Are you currently having back pain?

☐ Yes  ☐ No

Is it an on-going injury or do you have flare-ups?
☐ On-Going  ☐ Flare-Ups

What makes your back pain feel better?: _______________________________
What makes your back pain feel worse?: _____________________________

Does back injury affect your daily activities other than skating?:
☐ Yes  ☐ No

Does back pain affect your training?
☐ Yes  ☐ No

Was there ever a diagnosis made?
☐ Yes  ☐ No

If yes, who made the diagnosis?: __________________________

Did you get medical attention or treatment for your back pain?:
☐ Yes  ☐ No

If yes, what type: ________________
Did you take time off from skating?
  □ Yes  □ No

If yes, for how long? ______________

Did you have a restricted return to the ice after your injury?
  □ Yes  □ No

If yes, what type?: ______________

Have you injured your back more than once? New, exacerbation
  □ Yes  □ No

Do you currently receive on-going treatment?
  □ Yes  □ No

Please describe as much as possible any other injuries you have experienced over the past 5 years skating:
Appendix E

Muscle Strength and Flexibility Assessment
Biomechanic and Physical Assessment Screening

TO BE COMPLETED BY PROVIDER

Today’s Date: ___ / ___ / _______

Date of Birth: ___ / ___ / _______

Sex: _______

Height (cm): _______

Weight (lbs): _______

FLEXIBILITY

Ankle:
- Passive Plantarflexion
  - Left ____° Right _____°
- Passive Dorsiflexion
  - Left ____° Right _____°

Hip: Leg Straight
- Flexion-Supine
  - Left ____° Right _____°
- Extension-Prone
  - Left ____° Right _____°
- Abduction-Supine
  - Left ____° Right _____°
- Thomas test
  - Left ____° Right _____°

Shoulder Internal Rotation (Standing)
  - Left ____° Right _____°

Arm abduction
  - Left ____° Right _____°

Quadriceps
- Prone
  - Left ____° Right _____°
- ITB/Ober Test
  - Left ____° Right _____°
Manual strength muscle testing
Scale: 0-5

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Left</th>
<th>Right</th>
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<tbody>
<tr>
<td>Hip adduction</td>
<td>_____</td>
<td>_____</td>
</tr>
<tr>
<td>Hip abduction</td>
<td>_____</td>
<td>_____</td>
</tr>
<tr>
<td>Hip extension</td>
<td>_____</td>
<td>_____</td>
</tr>
<tr>
<td>Ankle plantar flexion</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Ankle dorsiflexion</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Ankle eversion</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Ankle inversion</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Deltoids</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Subscapularis</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Serratus</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Abdominal Angle</td>
<td>_____°</td>
<td></td>
</tr>
</tbody>
</table>

Push Ups - # correct _________________

Side Plank - time held correctly ______

**Vertical jump**

A. Height (inches) reached for two foot jump:
   #1: _____ #2: _____ #3: _____
   Average height: _____

B. Height reached (inches) with left foot:
   #1: _____ #2: _____ #3: _____
   Average height: _____

C. Height reached (inches) with right foot:
   #1: _____ #2: _____ #3: _____
   Average height: _____

**SQUAT**

<table>
<thead>
<tr>
<th>Sneakers: Angle (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder-hip-knee</td>
</tr>
<tr>
<td>Hip-knee-ankle</td>
</tr>
<tr>
<td>Knee-ankle-toe</td>
</tr>
<tr>
<td>Shoulders-Pelvis</td>
</tr>
</tbody>
</table>

Skates: Angle (degrees)

| Shoulder-hip-knee         |
| Hip-knee-ankle           |
| Knee-ankle-toe           |
| Shoulders-Pelvis         |
APPENDIX F

Ethical Approval Letter
Boston Children’s Hospital
Office of Clinical Investigation
380 Longwood Avenue
Boston, MA 02115
phone 617-355-7052, fax 617-730-0226

Principal Investigator: Ellen Geminiani, MD
Protocol Number: IRB-P00007021
Protocol Title: The prevalence of back injuries amongst figure skaters in relation to their functional movement
Date: February 14, 2013

NOTICE OF EXPEDITED APPROVAL
IRB Approval Date: 1/25/2013
IRB Activation/Release Date: 2/14/2013
IRB Expiration Date: 1/24/2014

The Committee on Clinical Investigation has approved the above referenced protocol through expedited review procedures. We are now able to release this approval to you since you have adequately responded to the Committee’s questions and concerns.

Risks were determined to be minimal with potential for direct benefit.

The Committee has determined that only one parent/guardian is required to provide permission for their child to participate in this study.

Assent is required from those subjects capable of understanding the research and its ramifications. If you determine a particular child is not capable of providing assent, you will need to provide justification on the informed consent after the parental signatures.

The approved consent form is available online through the CHB Informed Consent Library. To obtain the consent form, please go to http://chb.cffapps.research.conents. The ICLibrary should be accessed each time you need a consent form to ensure that the current version of the consent is always used. Do not store the consent forms on your computer or make copies for future use. Note that the activation/expiration date on the consent form can only be changed or modified by the staff of the Clinical Investigation Office. Please also note that subjects cannot be enrolled in a study if the consent form has expired. A copy of the signed consent should be kept in your files. It is our understanding that consent forms will be stored in the research record. The subject/family must also be given a signed copy.

Please note that CCI Staff have edited your consent form(s) to employ the new required headers, signature pages, and HIPAA language.

The occurrence of unanticipated problems should promptly be reported to this office. Any revisions, amendments, or changes to the protocol require prior Committee approval. The Committee has asked this office to notify investigators that clinical investigation protocol files are subject to audits at some future time.

Sincerely,

[Signature]
Sima Napoleon, IRB Administrator
For the Committee on Clinical Investigation

66
REFERENCES


Bloch, R. (1999). Figure Skating Injuries. Recreational Sports Injuries, 10(1), 177-186.


Sewing, J. (2010, February 17). Figure Skating is beautiful on the ice, brutal on the body. Houston Chronicle. Retrieved March 4, 2013, from http://www.chron.com/news/health/article/Figure-skating-is-beautiful-on-the-ice-brutal-on-1696548.php#photo-1219736

United States Figure Skating (2013). Retrieved January 23, 2013 from www.usfsa.org


VITA

DAVID A. LEENEN
dleenen@bu.edu (617)-756-3395
Year of Birth: 1989
Local Address: 761 Harrison Avenue, #207, Boston, MA, 02118
Permanent Address: 198 Lisgar Road, Ottawa, Ontario, Canada K1M 0E6

Education
2011 - Present Boston University School of Medicine, Boston, MA
  - 2 year graduate program, M.A. Medical Sciences
2007 - 2011 Boston University (Sargent College), Boston, MA
  - B.Sc in Human Physiology
  - Dean's list, Spring 2011
2003 - 2007 Ashbury College, Ottawa, ON, Canada
  - Certificates of International Baccalaureate
  - Scholar Role (overall average above 85%)
2011 Massachusetts Emergency Medical Technician Basic (EMT-B) certification

Scholarships
2010 - 2011 U.S. Figure Skating Association Memorial Fund Academic Scholarship

Clinical Work Experience
2012 - present Emergency Medical/Clinical Care Technician at Tufts Medical Center

Clinical Research Training
2011 (summer) Harvard School of Public Health: internship at Office of Human Research Administration; worked in the Quality Improvement Program of the Institutional Review Board and attended monthly IRB meetings
2010 (summer) Dana Farber Cancer Institute, (Boston, MA); worked with medical scientists to update the sarcoma tumor bank
2010 - present Completed yearly Collaborative Institutional Training Initiative (CITI) program; research ethics education to all members of the research community
2012 0 present Tutoring at Boston University School of Medicine,

Volunteer Activities
2003 - 2011 Performer in numerous local and regional skating shows raising funds for local charities and acting as a skater ambassador
Extra-Curricular Activities

Independent Sports

1996 - 2011  Figure Skating, national and international competitor in singles and pairs

2010 - 2011  -Member of U.S. Figure Skating National Reserve Team
             -Competitor at International Skating Union Junior Grand Prix,
              Dresden, Germany, September 2010 (Junior Pairs), 7th
             -Eastern Section U.S. Championships, November 2010 (Jr pairs), 1st
             -U.S. National Figure Skating Championships, Jan. 2011 (Jr pairs), 9th

2009 - 2010  -U.S. National Figure Skating Championships (Novice pairs), 9th
             -Eastern Section U.S. Championships (Novice pairs), 2nd
             -Eastern Section U.S. Championships (Junior Men), 11th
             -New England Regional Championships (Junior Men), 3rd


Boston University

2007 - 2011  Member of Intercollegiate Figure Skating Team
             -National Champions in 2009 and 2010, 3rd place in 2011

2007 - Present  Active member of intramural sports including broomball, floor hockey
                and basketball