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The Biomechical Analysis of the Kinetics and Kinematics for Three Figure Skating Jumps

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THE BIOMECHICAL ANALYSIS OF THE KINETICS AND KINEMATICS FOR THREE FIGURE SKATING JUMPS

by

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The problem of this investigation was to describe the kinetics and kinematics of three figure skating jumps: axel, double toe loop, and double loop. Specifically, the researcher investigated impact force, kinetic energy, and selected kinematic variables of female skaters during the landing phase of the three figure skating jumps. Kinetic energy and impact force were calculated during three phases of landing: Initial, Mid, and Final. Each of these phases represented a third of the time spent in landing each of the jumps. The kinematic variables measured during the landing phase of the jumps were vertical velocity, horizontal velocity, shoulder rotation, hip rotation, thigh/trunk angle, trunk inclination, and knee angle. The purpose of the study was to establish a better understanding of the stresses placed on a skater's body when executing jumps. It was intended that the analysis of figure skaters would provide evidence of strength and other physical attributes necessary to assure success in learning figure skating jumps. Results showed that the better jumpers experienced greater impact forces and kinetic energy for all jumps and dissipated the impact force over a greater time when compared to the poorer jumpers. The lack of ability of the poorer jumpers to dissipate the forces over time resulted in a greater impact during a shorter time of the landing phase and probably was responsible for the poor form and falls that resulted. Similar shoulder and hip rotations were observed in all subjects. However, the better jumpers had a more upright trunk position during landing than the poorer jumpers.

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Laura Blazok

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CHAPTER I

INTRODUCTION

Seventy percent of adult North Americans will be struck by a severe episode of low back pain at some point in their lifetimes (Micheli & McCarthy, 1998). Low back pain does not occur to just adults. Many young athletes are becoming susceptible to low back pain, and sometimes the pain is a sign of a major injury. One of the possible causes of this pain and of these injuries is excessive compression within the spinal column. Many young athletes who participate in activities where jumping is a major component expose themselves to these compression forces. It is during the landing phase that the spine is subjected to compressive stress with poor posture being a potential exacerbating variable. Few studies have examined the mechanics of athletes performing jumping skills in the landing phase.

Currently, athletes are often required or encouraged to begin intense training and competition at a very young age. In activities where jumping occurs often the low back is put under undue stress. Low back injuries or pain can end a promising career for young and old athletes engaged in jumping activities (Micheli & McCarthy, 1998). Therefore, it is important to know the stresses an athlete is subjected to during practice and competition that might be related to a future injury. With this knowledge preventative measures can be taken to decrease the risk of injury. Studies describing the mechanics of figure skating jumps may help prevent low back injuries in skaters. The kinematics and kinetics of figure skating jumps will provide valuable information concerning the physical preparation and demands of the skater to learn and practice jumps in a safe manner. Current literature on the biomechanics of figure skating jumps is limited. Due to the current interest and popularity of the sport of figure skating, information on the mechanics of figure skating jumps would be of benefit to the skater and the coach.

Statement of the Problem

The problem was to describe the kinetics and kinematics of three figure skating jumps: (1) single axel, (2) double toe loop, and (3) double loop jump. Specifically, the researcher investigated the impact force, kinetic energy, and posture of female skaters during the landing phase of the three different skating jumps.

Delimitations

The study was delimited to the following:

1. Four elite, female figure skaters from Southwestern Michigan, 18 to 25 years of age, volunteered to serve as the subjects for this study.

2. Subjects were screened for orthopedic injuries that occurred within the last 6 months; those who had injuries within the last 6 months failed the screening and were not accepted as subjects for this study.

3. Subjects performed three trials for each of the three jumps being tested: the axel, the double toe loop, and the double loop.

4. The subjects were videotaped using the Peak Motus 3-D System, Peak Performance, Inc., Inglewood, CO.

5. Only the landing phase for each of the three jumps was analyzed.

Limitations

The following limitations should be noted when interpreting the results of this study:

1. The small sample size could jeopardize external validity.

2. The group of the skaters who served as subjects in this study may limit the interpretation of the study.

Basic Assumptions

The following conditions were assumed to have occurred in the conduct of this study:

1. The equipment utilized in the data collection procedure performed within the specifications indicated by the respective manufacturers.

2. Subjects performed to the best of their ability on all trials and conditions associated with data collection.

3. The individuals who helped in the data collection complied with the standard procedures established for the study.

Research Hypotheses

The following hypotheses were tested:

1. Consistent mechanics existed among the three trials for each of the three jumps.

2. Similar impact forces occurred for the three jumps within and between subjects.

3. The kinetic energy during the landing phase of the three jumps will be similar within and between subjects.

Definitions

The following definitions are pertinent to this study:

1. *Center of gravity:* The point at which the body's mass is concentrated, the balance point of a body, and the point around which the sum of the torques of the segmental weights is equal to zero. The point of application found in all objects where the force of gravity pulls vertically downward. Center of gravity is also called center of mass (Kreighbaum & Barthels, 1996).

2. *Centripetal force:* The force directed radial toward the center of a rotating body or object. This force causes the body to travel in a circular path (Kreighbaum & Barthels, 1996).

3. *Digitize:* A process used to plot or identify the Cartesian coordinates of a point on an image for quantitative analysis. Digitizing is usually performed with a computer interfaced with video equipment (Kreighbaum & Barthels, 1996).

4. *Dynamics:* Mechanic associated with evaluating systems in motion (Kreighbaum & Barthels, 1996).

5. *Force:* That which causes or tends to cause a change in a body's motion or shape. A force is a push or a pull (Kreighbaum & Barthels, 1996).

6. *Kinesthesis:* The study of perception of segmental and body position and movements in space (Kreighbaum & Barthels, 1996).

7. *Kinetics:* An area of study that is concerned with mechanics that act on a system to cause motion (Kreighbaum & Barthels, 1996).

8. *Torque:* What causes angular or rotary motion. The magnitude is equal to the product of a force and the perpendicular distance from the line of action of the force to the axis of rotation (Kreighbaum & Barthels, 1996).

CHAPTER II

REVIEW OF LITERATURE

Introduction

At landing, figure-skating jumps produce impact forces on the spine in the form of compression. This study was developed to understand the stresses placed on the body as a result of these jumps. Few studies have been completed, due to the difficulty in calculating the kinetics of skating jumps. The sport of figure skating has become very popular within the last 5 years. For this reason it is important to understand the stresses related to landing from jumps and what the skaters can do to minimize stress and prevent injuries. Low back pain and spinal injuries can cause long-term effects; therefore it is important to understand what kind of force is being put on the body while performing these jumps. The problem was to investigate the kinetics and kinematics of three figure skating jumps: (1) single axel, (2) double toe loop, and (3) double loop jump. Specifically, the researcher investigated the impact force, kinetic energy, and posture during the landing phase of the three jumps. The review of literature covers the following topics pertinent to this study: (a) figure skating jumps, (b) biomechanics of landing, (c) low back pain, (d) back biomechanics, and (e) summary.

Figure Skating Jumps

The explanations for the axel, double toe loop, and double loop jumps are described for a right-foot skater. A right-foot skater is one who uses the right foot as the take-off foot to generate the forces necessary to propel the body upward.

Axel

The axel is considered the "break" jump by skaters and coaches because the physical, technical, and psychological demands effectively separate competitors into novice, regional, national, and international levels (Albert & Miller, 1996). The axel is most commonly performed by: (a) stepping forward on the left foot, outside skate edge; (b) jumping forward off the left foot while the right leg provides momentum by a high knee lift action; (c) initiating rotation with right hip transverse adduction; (d) rotating around the longitudinal axis one and a half revolutions; and (e) landing backwards on the right foot, outside skate edge. Differences have been reported between the number of revolutions completed in the air and vertical velocity and angular momentum about an axis through the center of gravity prior to takeoff (Albert & Miller, 1996).

Double Toe Loop

The double toe loop has a different take off than the axel. The double toe loop is most commonly performed by: (a) stepping forward on the right inside skate edge; (b) turning 180° onto the right outside skate edge; (c) reaching back with the left leg and toeing into the ice; (d) pivoting 180° on the left leg; (e) jumping off the left foot while the right leg provides momentum by a high knee lift action, (f) initiating rotation with right hip transverse adduction; (g) rotating around the body's longitudinal axis one and a half revolutions; and (h) landing backwards on the right foot, outside skate edge.

Double Loop Jump

The double loop is the most difficult jump of the three because the skater takes off and lands on the same foot. The double loop jump is most commonly performed by: (a) gliding backwards with the weight on the back skate and on the right-outside blade edge; (b) jumping and extending the right leg while using the arms and left leg to gain height; (c) rotating 720° to the left; and (d) landing backwards on the right leg, outside skate edge.

Low Back Pain

Of the numerous complaints of musculoskeletal disabling conditions in the general population, the complaint of low back pain is undoubtedly predominant (Cailleit, 1980). Similarly in skaters, much of the low back pain comes from overuse. Thousands of girls skate 5 to 20 hours per week and compete regularly in local and national events. In single events, injuries are related to overuse and the skate boot, as well as to collision with the ice surface when landing from the jumps (Smith, 1997).

The clinical manifestations of low back pain are the same in athletes as in the general population. Low back problems constitute about 5% of all time-lost injuries in sports (Rovere, 1987). Most often there is acute onset of pain with a sensation of pulling, snapping, or giving way. Spasms usually follow, and the ability to compete is lost. The severity of pain and spasm can vary greatly from athlete to athlete (Ferguson, 1974). Not only can chronic back pain be painful, but also it may be indicative of stress fractures that are very serious and hard to recover from. Another somewhat common cause of low back pain is the pars articularis defect or spondylolysis. This condition can be aggravated by the three jumps associated with this study. If not diagnosed properly and early, most back injuries can become chronic and can force the athlete to withdraw from competition.

Back Biomechanics

Reversed curves appear in the cervical spine as a baby begins to bear weight and hold up his or her head. The head, thoracic area, and pelvic area form the rigid portions of the total span of the trunk, with the lordotic, cervical, and lumbar areas acting as springs (Gould, 1990). When doing the skating jumps, the magnitude of the kinetics and kinematics at takeoff determines the height and time spent in the air. Much of this is due to the projection angle and the body's shape (Kreighbaum & Barthels, 1996). The vertebral column consists of 33 bones. All the vertebrae are similar in structure. The spinous and transverse processes serve as handles for the attachments of the deep and superficial muscles of the back. Depending on the direction of the lines of action of these muscles, the force of pull on the processes may cause forward, backward, or lateral bending, or small amounts of rotation of the superior vertebra on the adjacent inferior vertebra. All of these combined motions of the vertebral column can create a large amount of rotation (Kreighbaum & Barthels, 1996).

Summary

This study is imperative to the future not only of the new young figure skaters but also of all young athletes. Low back pain and injuries due to impact forces, torque, and posture during landing phases are becoming more common in figure skaters. A goal for future figure skating research is to determine the magnitude of the forces of compression during the landing phase of the skating jumps. The results found from this study should lead to a more thorough understanding of the landing stresses associated with figure skating jumps.

CHAPTER III

METHODS AND PROCEDURES

Introduction

The problem was to investigate the kinetics and kinematics of three figure skating jumps: (1) axel, (2) double toe loop, and (3) double loop jump. Specifically, the researcher investigated the impact force, kinetic energy, and posture during the landing phase of the three jumps. This chapter has been divided into the following subtopics: (a) introduction, (b) subjects, (c) instrumentation, (d) data collection procedures, and (e) experimental design.

Subjects

Subjects were four Southwest Michigan skaters 18 to 25 years of age. All potential subjects were screened for physical problems that might warrant their exclusion from the study. See Appendix A for the screening questionnaire. Volunteers were excluded from the study if they: (a) experienced an orthopedic injury to the extremities during the past 6 months, (b) had not performed the jumps in practice and competition during the past year, (c) were recovering from muscle soreness, or (d) had not practiced during the week prior to data collection due to a cold or flu. Subjects read and signed a consent form prior to participating in the study (see Appendix B). Approval for conducting this study was given by Western Michigan University's Human Subjects Institutional Review Board (see letter in

Appendix C). All data collection occurred at Lawson Ice Arena in Kalamazoo, MI. Subjects were involved in one 1-hr session of data collection.

Instrumentation

The following instruments were used to collect and analyze the data for this study:

1. Two Panasonic cameras, AG 450 and AG 5100, New Jersey, were used to record the jumps.

2. Peak Motus 3-D System created by Peak Performance Technologies, Inc., Inglewood, CO, was used to collect and analyze the data.

3. The Gateway 2000 computer (VX1100 monitor, and E31110 CPU), Sioux City, SD, was interfaced with the Peak hardware and ran the Peak software.

Data Collection Procedures

The data collection occurred in three phases: (1) site set-up, (2) video taping, and (3) video taping analysis.

Site Set-up

The data collection site was arranged according to the following specifications:

1. A scale apparatus containing eight arms with known X, Y, and Z coordinates covering an area approximately two cubic meters was used to scale and identify points in space. Four arms projected diagonally from the top and four

projected diagonally from the bottom of the central block. Each arm contained three white balls (2-cm radius) with known X, Y, and Z coordinates.

2. The field of view of each camera was adjusted to ensure that all 24 calibration points were visible in both cameras. The cameras were placed perpendicular to one another facing the center ice circle.

3. The cameras were gen-locked to assure that both cameras were recording the motion at the same time. An Event and Camera Synchronization Unit, Peak Performance Technologies, Inc, Inglewood, CO, was used to gen-lock the cameras in real-time.

4. The cameras were set approximately 30 m from the area where the subjects performed the jumps.

Videotaping

The data collection lasted approximately 1 hour for each subject. All subjects followed the same procedures upon arriving at the testing site. Subject procedures are listed below:

1. Each subject filled out a consent form and a screening questionnaire prior to participating in the study.

2. The subjects' weights were measured and their skates' weights were measured.

3. The skates' center of gravity was located by suspending each skate from a small metal rod from which a plumb lines was attached. Each skate was suspended first by the inside of the rear stanchion of the blade and then by the posterior side of the middle stanchion, under the ball of the foot. The center of gravity of the boot was defined as the point where the two lines of gravity intersected.

4. Reflective markers were placed on the hand, wrist, elbow, shoulder, boot toe, ankle, knee, hip, midpoint of right and left hips, sternum, ear, top of head, and at the center of gravity of the skate boots.

5. The subject was oriented to the facility and to the area on the ice where they would perform the jumps. Skaters were instructed to perform the jumps so the landing occurred in the center ice circle within a two cubic meter area.

6. The skaters performed a 15-minute warm-up and practice session.

7. Following the warm-up, the skaters performed three axels, three double toe loops, and three double loop jumps in a random order.

Videotape Analysis

Three trials for each jump per subject were analyzed. The data from each camera were filtered using a Butterworth filter set at 6 Hz. A direct linear transformation mathematical procedure was used to calculate three-dimensional coordinates from the two-dimensional coordinates collected from each camera. The three-dimensional coordinates were used to calculate linear and angular displacements, linear velocities and accelerations, and the location of the body's center of gravity.

The motion analyzed was the landing phase for each of the jumps. The analyses began approximately 0.05 s before the skate contacted the ice and ended after the body's center of gravity reached its lowest vertical position. This motion contained the eccentric phase of landing plus 0.05 s before and after the phase began and ended.

Research Design

This study of the mechanics of the landing phase of the three figure skating jumps is descriptive in nature. The intent of the researcher was to describe the impact force, kinetic energy, and posture during the landing phase of three figure skating jumps. For the purpose of describing mechanics, means and standard deviations were utilized. Also, the consistency of subjects' performances was examined. Performance consistency was examined descriptively.

The dependent variables were measured for the landing phase of the three jumps. The landing phase was divided into three subphases: (1) Initial, (2) Mid, and (3) Final. Each of these phases represented one third of the time spent in landing the jump. The variables measured included:

1. Vertical velocity of the body's center of gravity at the beginning of the Initial Phase.

2. The horizontal velocity of the body's center of gravity at the beginning of the Initial Phase. This velocity was the resultant of both horizontal directions.

3. Kinetic energy was measured during each of the phases using the formula, $KE = \frac{1}{2} g v^2$. After kinetic energy was calculated, it was divided by body mass to create a relative measure making comparisons among subjects meaningful.

4. Impact force was measured during each of the phases using the formula, $F = (m v^2)/2d$. Impact force was also divided by body mass to create a relative measure.

5. Shoulder rotation was measured between two lines. The lines were between the right and left shoulder joints and the z-axis.

6. Hip rotation was measured between two lines. The lines were between the right and left hip joints and the z-axis.

7. Trunk inclination was measured between the line bisecting the trunk and a vertical axis passing through the trunk.

8. Knee joint angle was measured on the posterior side of the lower extremity by two lines. One line was from the hip joint to the knee joint and the other line was from the knee joint to the ankle joint.

9. Thigh/trunk angle was the angle formed between the line that bisected the trunk and the line from the right thigh to the right knee.

CHAPTER IV

RESULTS

Introduction

The problem of this study was to investigate the kinetics and kinematics of three figure skating jumps: (1) single axel, (2) double toe loop, and (3) double loop jump. Specifically, the researcher investigated the impact force, torque, and posture during the landing phase of the three jumps. The following six variables were compared for each jump across subjects: (1) linear velocity, (2) displacement of the center of mass, (3) kinetic energy, (4) impact force, (5) mean joint angles at touchdown, and (6) joint range of motions during the landing phase. The landing phase was broken into three equal parts according to time. The phases will be referred to as initial landing, middle landing, and final landing.

Characteristics of Subjects

The four subjects were student volunteers from Southwestern Michigan. Due to the difficulty of the jumps, only four subjects were able to complete the study. The subjects ranged in age from 18 to 25 years with a mean age of 22 years. The skill level of the four subjects represented a wide range. This may have been due to practice time and experience. Subject 1, the best skater of the group, was a senior free singles and pairs skater. Subject 4, the second best skater was a junior free skater. Subject 2, the third best skater, was also a junior free skater. Subject 3, the fourth best skater, was a junior free skater. The performance inconsistencies that occurred during this study were more prevalent in Subjects 2 and 3, with Subject 3 exhibiting the least consistency. Subject 3 had less experience in both practice time and competition than Subjects 1 and 4. Subject 2 was the least skilled of all the subjects but more consistent than Subject 3. The inconsistency of the performance of both Subjects 2 and 3 made data interpretation difficult.

Linear Velocity

Linear velocity data calculated for the three jumps—axel, double toe loop, and double loop—included vertical velocity and horizontal resultant velocity. The linear velocity data for the three jumps are presented in Table 1. The linear velocities were calculated for each subject. The velocity value for each subject is the mean value for the three trials. The standard deviation provided information concerning the consistency of the subjects' performances during the three trials.

Axel

The axel jump was the least difficult and most basic of all three jumps. All four subjects successfully completed this jump; however, the performance of Subject 1 was superior to the other three subjects. The vertical velocities of the center of mass were −1.69 mps, −0.69 mps, −1.07 mps, and −1.10 mps for Subjects 1, 2, 3, and 4, respectively. The higher the vertical velocity magnitude, the higher the jumper traveled vertically in the air during the axel jump. Therefore, Subject 1 had the longest flight time, Subjects 3 and 4 exhibited similar flight times, with Subject 2 exhibiting the shortest flight time. The standard deviations for Subjects 1, 2, and 4 were all low and similar in value. Subject 3 had the greatest trial variability.

Table 1

Descriptive Statistics for Velocity Across Trials for the Axel, Double Toe Loop, and Double Loop Jumps

Subject	Jump	*M* Vertical	*SD* Vertical	*M* Horizontal
1	A	–1.69	0.56	4.58
2		–0.69*	0.53*	2.17*
3		–1.07*	0.72*	2.91*
4		–1.10	0.58	3.04
1	DT	–1.23	0.47	4.21
2		–0.99*	0.78*	2.39*
3		–1.36*	0.48*	2.03*
4		–0.87	0.62	1.56
1	DL	–1.20	0.49	2.59
2		–1.12*	0.39*	1.89*
3		–0.79**	0.93**	0.57**
4		–0.94	0.62	1.28

Note. Units of measure are mps.
* Subject fell on one of the three trials. ** Subject fell on all three trials.

Therefore, Subjects 1, 2, and 4 were more consistent across the three trials than Subject 3. A higher flight time would provide time to execute the axel properly and prepare the body for landing. If the flight time was short, the preparation time for landing would be rushed and the dynamic equilibrium during landing would be affected. This could be the reason that Subject 3 had more inconsistency among the three trials compared to the other three subjects.

The horizontal resultant velocity was the actual velocity of the center of mass in the transverse plane. It is the resultant of the two horizontal dimensions. This velocity should be relatively high since the skaters are moving horizontally across the ice prior to the jump. Some horizontal momentum is transferred to vertical momentum during the takeoff phase of the jump. Upon landing the skater continues to move horizontally across the ice to help reduce the force of impact and to assist with the dynamic equilibrium associated with landing. For these reasons, if the resultant horizontal velocity during the landing phase is high, a more successful performance will occur. The resultant horizontal velocity values for the subjects from highest to lowest were 4.58 mps for Subject 1, 3.04 mps for Subject 4, 2.91 mps for Subject 3, and 2.17 mps for Subject 2.

Double Toe Loop

The double toe loop is the least difficult of the double jumps. Therefore, its difficulty lies between the axel and the double loop. All four subjects attempted this jump; however Subject 4, one of the better skaters, had trouble performing the jump during filming. The vertical velocities of the center of mass were –1.23 mps, –0.99 mps, –1.36 mps, and –0.87 mps for Subjects 1, 2, 3, and 4, respectively. The greater the vertical velocity, the greater the vertical height the jumper achieves during flight. All four subjects achieved a lower vertical velocity when performing the double toe loop in comparison with performing the axel. Subject 3 had the highest vertical velocity, –1.36 mps; Subject 1 had the second greatest vertical velocity, –1.23 mps; Subject 2 had the third highest vertical velocity of –0.99 mps; and Subject 4 had the lowest vertical velocity of –0.87 mps. The standard deviations for Subjects 1 and 3 were small and similar in value. Therefore, these subjects' performances across the three trials were more consistent than Subjects 2 and 4. The results for this jump show that Subject 4, although one of the better performers, did not perform consistently across trials and produced short flight times due to a low vertical velocity. When the flight time is short, the preparation for landing is compromised, resulting in a rushed and unstable landing. This could be the reason why Subject 4 was inconsistent across the three trials compared to the other three subjects.

The horizontal resultant velocity represented the actual velocity of the center of mass in the transverse plane or the resultant velocity of the two horizontal dimensions. This velocity should be relatively high since the skaters are moving horizontally across the ice prior to executing the jump. Some of this horizontal momentum will be transferred to vertical momentum during the takeoff phase of the jump. Upon landing the skater should continue to move horizontally across the ice to assist in reducing the force of impact and to assist with the dynamic equilibrium associated with landing. For these reasons, if the resultant horizontal velocity during the jump is high, a better performance occurs with less stress and potential injury to the skater. The horizontal resultant velocity values for the subjects from highest to lowest were 4.21 mps for Subject 1, 2.39 mps for Subject 2, 2.03 mps for Subject 3, and 1.56 mps for Subject 4. Subject 1 produced the highest horizontal resultant velocity and produced the best performance. Subject 4 produced the least horizontal resultant velocity and could not successfully perform the jump. A failure to create a high horizontal resultant velocity increases the difficulty of performing this jump successfully.

Double Loop Jump

The double loop jump was the most difficult of the three jumps performed. Three of the four subjects successfully completed the jump. Subject 1 was most consistent, while Subject 3 fell on all trials. The average vertical velocity of the center of mass during the landing phase was –1.20 mps, –1.12 mps, –0.79 mps, and –0.94 mps for Subjects 1, 2, 3, and 4, respectively. The higher the vertical velocity, the higher the skater jumps in the air during the double loop jump. The standard deviations for Subjects 1 and 2 were small and similar in value. Therefore, these subjects' performances across the three trials were more consistent than Subjects 3 and 4, whose standard deviations were larger. A greater flight time provides time to execute the double loop jump properly and prepare the body for landing. This aspect is especially important in this jump because the takeoff position for this jump makes a large vertical velocity difficult to attain. If the flight time is short, the preparation for landing will be rushed and dynamic equilibrium during landing will be affected. Subject 3 had difficulty in landing this jump as evidenced by her more variable average vertical velocity. The results for Subject 3 were thought to be due to the fact that she fell when performing this jump during all three trials.

The horizontal resultant velocity was the actual velocity of the center of mass in the transverse plane or the resultant of the two horizontal dimensions. This velocity should be large in magnitude since the skaters are moving horizontally across the ice prior to the jump. Some horizontal momentum from the approach is transferred to vertical momentum during the takeoff phase of the jump. Upon landing the skater needs to continue to move horizontally across the ice to help reduce the force of impact and to assist with the dynamic equilibrium associated with landing. For these reasons, if the resultant horizontal velocity during the landing phase is high, a better performance will occur. The horizontal resultant velocity values for the subjects from highest to lowest were 2.59 mps for Subject 1, 1.89 mps for Subject 2, 1.28 mps for Subject 4, and 0.57 mps for Subject 3. Subject 1 produced the highest horizontal resultant velocity and the best performance. Subject 3 produced the lowest horizontal resultant velocity and failed to land any of the three trials. The low horizontal velocity and short flight time (low vertical velocity) contributed to the inability of Subject 3 to successfully land this jump.

Velocity Summary

The average vertical velocity for each subject decreased as the difficulty of the jumps increased. Subject 1 maintained relatively consistent average vertical velocities, horizontal resultant velocities, and standard deviations across the jumps, whereas Subjects 2, 3, and 4 were inconsistent across jumps. The inconsistencies may be due to lack of experience and practice time. Subject 1 had more experience as a skater, competed at a higher level, and practiced more than the other subjects.

Kinetic Energy and Impact Force

Vertical kinetic energy and impact were calculated for the landing phase of the three jumps: (1) axel, (2) double toe loop, and (3) double loop. Calculations were based on a motion that began approximately 0.053 s prior to the blade of the plant skate contacting the ice and ended when the negative vertical component of the center of gravity displacement ceased. This landing phase was divided into three intervals: (1) Initial Landing or the first third of the landing phase, (2) Mid-Landing or the middle third of the landing phase, and (3) Final Landing or the last third of the landing phase. To make comparisons between subjects, the results for both kinetic energy and impact forces were calculated per unit of kilogram of body mass. See Tables 2 and 3 for the kinetic energy and impact force results, respectively.

Table 2

Mean Kinetic Energy During the Landing Phases for the Axel, Double Toe Loop, and Double Loop Figuring Skating Jumps

		Landing Phases								
		Initial			Mid			Final		
Subject	Jump	*M* $N \cdot m \cdot kg^{-1}$	*M* $N \cdot m$	*SD*	*M* $N \cdot m \cdot kg^{-1}$	*M* $N \cdot m$	*SD*	*M* $N \cdot m \cdot kg^{-1}$	*M* $N \cdot m$	*SD*
1	A	2.64	164.91	23.05	1.39	86.94	13.09	0.47	29.11	8.11
2		0.87	59.51	3.36	0.19	13.02	4.75	*0.02	1.15	0.33
3		1.32	98.82	5.33	0.27	20.20	3.34	0.06	4.57	5.54
4		1.37	81.03	5.31	0.47	27.86	2.97	0.07	4.30	2.17
1	DT	1.49	93.12	9.12	0.64	39.83	2.93	0.15	9.19	0.59
2		1.72	117.81	6.88	0.24	16.49	9.31	*0.06	4.21	1.60
3		1.30	97.46	5.94	0.14	10.17	6.87	*0.85	64.41	36.12
4		1.37	80.84	12.43	0.32	18.88	9.18	0.04	2.35	1.60
1	DL	1.46	91.56	7.45	0.69	43.21	9.90	0.19	11.97	3.28
2		1.35	92.21	16.18	0.70	47.69	40.02	*0.62	42.63	6.55
3		1.40	105.31	12.96	0.73	54.44	54.56	**		
4		1.09	64.75	5.29	0.17	10.04	5.69	0.02	1.13	0.86

*Numbers calculated on two trials. **Missing data; subject fell.

Table 3

Mean Impact Forces During the Landing Phases for the Axel, Double Toe Loop, and Double Loop Figuring Skating Jumps

		Landing Phases								
		Initial			Mid			Final		
Subject	Jump	*M* $N \cdot kg^{-1}$	*M* $N \cdot m$	*SD*	*M* $N \cdot kg^{-1}$	*M* $N \cdot m$	*SD*	*M* $N \cdot kg^{-1}$	*M* $N \cdot m$	*SD*
1	A	22.81	1425.42	104.45	15.47	966.75	195.84	7.38	461.27	63.24
2		7.41	507.30	61.98	3.50	239.57	49.34	*1.02	70.14	7.76
3		10.06	754.89	97.45	4.42	331.38	94.63	*3.47	260.31	302.37
4		11.82	697.25	94.44	6.10	359.69	27.63	2.25	132.94	30.25
1	DT	12.73	795.32	30.31	7.95	496.74	122.87	4.16	260.23	70.91
2		11.36	778.02	183.93	4.86	332.91	124.15	*3.46	237.27	33.34
3		10.43	782.26	128.71	7.45	558.99	303.07	*6.74	505.32	220.70
4		7.96	469.47	27.73	3.16	186.20	67.47	0.62	36.68	40.91
1	DL	12.71	794.71	31.18	8.06	503.46	72.61	3.37	210.32	7.89
2		11.35	777.63	130.72	9.02	617.54	461.27	*9.85	675.05	144.46
3		7.93	594.60	226.43	3.98	298.49	37.24	**		
4		10.11	596.72	172.51	4.55	268.33	96.70	1.58	93.23	44.63

*Numbers calculated on two trials. **Missing data; subject fell.

Kinetic Energy

During the Initial Landing Phase the kinetic energy per kilogram of body mass demonstrated a similar result as that seen with vertical velocity. This would be expected since the measure was calculated relative to body mass. Therefore, Subject 1, who had the greatest flight time and highest vertical displacement, would have the greatest kinetic energy. This was true for the axel and double-loop jumps but not for the double-toe-loop jump. For the double-toe loop jump, Subject 2 had the greatest kinetic energy.

The relationship of most interest was how the kinetic energy dissipated over the three landing phases. Since the three phases represented the landing time divided into equal intervals, a gradual dissipation across the three phases would represent a smooth, controlled, and safe landing motion.

Axel

From Table 2, the percentages of kinetic energy dissipated during the Initial, Mid, and Final Phases of landing for the axel indicated were: (a) 47%, 35%, and 18%, respectively, for Subject 1; (b) 78%, 20%, and 2%, respectively, for Subject 2; (c) 80%, 16%, and 4%, respectively, for Subject 3; and (d) 65%, 37%, and 5%, respectively, for Subject 4. Looking at kinetic energy percentages dissipated across the three phases shows that Subject 1 handled the kinetic energy in a manner that produced a smooth flowing movement. Subject 4's Initial Landing was hard and thus her kinetic energy was not as gradually dissipated over the three phases compared to Subject 1. Subjects 2 and 3 had similar patterns of dissipating the kinetic energy across the phases. Both subjects had a hard landing indicative of the large percentages, 78% and 80%, respectively, that were dissipated during the Initial Landing Phase. During the Final Landing Phase, both Subject 2's and Subject 3's percentages were low, 2% and 4%, respectively. The hard initial landing and great initial dissipation of kinetic energy were a major factor in the poor skill performance exhibited by Subjects 2 and 3.

Double Toe Loop

The percentages of kinetic energy dissipated during the Initial, Mid, and Final Phases of landing for the double toe loop indicated were: (a) 57%, 33%, and 10%, respectively, for Subject 1; (b) 86%, 11%, and 3%, respectively, for Subject 2; (c) 89% for the Initial Phase for Subject 3; and (d) 77%, 20%, and 3%, respectively, for Subject 4. Subject 1's percentages for this jump were similar to those exhibited for the axel. Her performance for the double toe loop was the best of the three subjects who completed this jump. Subject 4 was able to execute the double toe loop; however, her form was not as good as Subject 1. The difference between Subject 1 and 4 was the landing. Subject 1's landing was controlled as indicated by the percentages of kinetic energy dissipated across the phases, while Subject 4 dissipated most of her kinetic energy during the first phase. Subjects 2 and 3 were not able to execute all three trials of the double toe loop. Out of the three jumps, both subjects fell once. Subject 3's performance was so poor that kinetic energy could not be calculated during the last two phases of landing. Both subjects lost control of the landing in the Initial Phase due to the high kinetic energy dissipated during that phase. The researcher believed that these subjects' falls were related not only to failure to dissipate kinetic energy but to the their inability to produce a high enough vertical velocity. Velocity is related to displacement of the body vertically in the air, thus creating the time necessary to complete the jump and prepare for landing.

Double Loop

Percentages of kinetic energy dissipated during the Initial, Mid, and Final Phases of landing for the double loop were: (a) 53%, 34%, and 13%, respectively, for Subject 1; (b) 48%, 6%, and 46%, respectively, for Subject 2; (c) 48%, 50%, and fell, respectively, for Subject 3; and (d) 84%, 14%, and 2%, respectively, for Subject 4. Again, when comparing subjects, the patterns for the double loop reflect similar findings to the other jumps. Subject 1 and 4 successfully competed all trials of the double loop. Between the two, Subject 1's performance was superior due to a more gradual dissipation of kinetic energy. Subject 4 hit the ground hard in the Initial Phase but was able to control the landing to compete the jump. Subject 2 fell during one of the trials, and Subject 3 fell during the Final Phase in all three trials. Both Subjects 2 and 3 had the lowest percentage of kinetic energy (less than 50%) dissipated during the Initial Phase. During the phases that these subjects fell, both were losing a large portion of their kinetic energy, 46% and 52% for Subjects 2 and 3, respectively. The researcher believed that the large proportion of kinetic energy dissipated during the final interval of the landing phase caused the muscular strength of the subject to focus on fast joint motion in the lower extremity first contacting the ice. If the opposite were true, a small amount of kinetic energy being dissipated during the Final Phase of Landing, the muscular strength of the subject would be focused on movement control and resulting in a smooth, more coordinated muscular response.

Kinetic Energy Summary

To produce a controlled landing motion for each of the jumps, the skater needs to dissipate the kinetic energy over time. If a large portion of the energy is dissipated quickly at the beginning of the landing phase, the forces associated with landing will be large. To avoid injury due to the force of landing, the skater often fell instead of continuing the linear motion into the next movement pattern. Subject 1 dissipated her kinetic energy more evenly over the three phases of landing of each jump when compared to the other skaters. This reduced the magnitude of the landing forces allowing her to complete the landing without falling. The other subjects dissipated most of their kinetic energy during the Initial Phase for the easier jumps (axel and double toe loop) and during the Final Phase for the hardest jump (double loop). This caused their performance to be poor and resulted in many falls.

Impact Force

During the Initial Landing Phase the impact force per kilogram of body mass indicated a result similar to that seen for vertical velocity and kinetic energy. This was expected since the impact force measure was calculated relative to body mass. Therefore, Subject 1, who had the greatest vertical velocity and kinetic energy, would have the greatest impact force. However, the impact was dissipated over a longer period of time.

The relationship of greatest interest was how the impact force for each jump was distributed over the three landing phases. Since the three phases represented the landing time divided into equal time intervals, the impact force should decrease by

33% across each phase. This would allow a smooth, controlled, and safe landing motion and put the skater in a position to continue a skating routine.

Axel

From Table 3, the percentages of the impact force distributed during the Initial, Mid, and Final Phases of landing for the axel were: (a) 32.18%, 35.47%, and 32.35%, respectively, for Subject 1; (b) 52.77%, 33.47%, and 13.77%, respectively, for Subject 2; (c) 56.06%, 9.44%, and 34.49%, respectively, for Subject 3; and (d) 48.39%, 32.57%, and 19.04%, respectively, for Subject 4. Examining the impact forces distributed across the three phases showed that Subject 1 did a better job of distributing the impact force than did Subjects 2, 3, and 4. The more even distribution across the phases allowed Subject 1 to control her landing motion and resulted in a smooth transition into the gliding motion following the landing. Subjects 2, 3, and 4 all completed the axel without falling; however, the distribution of the impact force across the three landing phases was not as evenly distributed. The result for these subjects could have been related to the small vertical velocities previously discussed.

Double Toe Loop

From Table 3, the percentages of the impact force distributed during the Initial, Mid, and Final Phases of landing for the double toe loop were: (a) 37.55%, 29.77%, and 32.68%, respectively, for Subject 1; (b) 57.22%, 12.32%, and 30.46%, respectively, for Subject 2; (c) 28.57%, 6.80%, and 64.62%, respectively, for Subject 3; and (d) 60.30%, 31.91%, and 7.79%, respectively, for Subject 4. Again, Subject 1 did a better job of distributing the impact force across the landing phases than did Subjects 2, 3, and 4. This result contributed to Subject 1's ability to control her landing motion and provided a smooth transition into subsequent movements. Subjects 2 and 3 fell on one of the three trials. Results for these two subjects were opposite of one another. Subject 2's impact was greatest during the Initial Phase. Subject 3's impact was greatest during the Final Phase. Subject 4's impact force distribution allowed her to complete the jumps without falling; however, her motion was not smooth and flowing. The percentages of impact across the phases indicated that she landed hard in the Initial Phase and Mid Phase. It is possible that her physical strength allowed her to deal quickly with the high impact force she experienced during the landing phases. During the Final Phase, she was able to transfer momentum into linear motion rather than falling like Subjects 2 and 3.

Double Loop

From Table 3, the percentages of the impact force distributed during the Initial, Mid, and Final Phases of landing for the double loop were: (a) 36.59%, 36.90%, and 26.51%, respectively, for Subject 1; (b) 20.53% for the Initial Phase for Subject 2; (c) 49.81% and 50.10% for the Initial and Mid Phases for Subject 3; and (d) 55.00%, 29.38%, and 15.63%, respectively, for Subject 4. Again, Subject 1 did a better job of distributing the impact force across the landing phases than did Subjects 2, 3, and 4. Again, this result contributed to Subject 1's ability to control her landing motion, allowing a smooth transition into subsequent movements. Subjects 2 and 3 fell on all three trials. Subject 2 experienced high impact force in the Mid Phase of the trials, and Subject 3 experienced high impact force in both the Initial and Mid Phases. Both Subjects 2 and 3 could benefit from strength training in conjunction with their jump practice.

Summary of Impact Force

Subject 1, the most successful of all the subjects, distributed the impact force across the three phases more evenly than Subjects 2, 3, and 4. This even distribution allowed the subject a greater opportunity to control the motion. Also, overall lower extremity strength could have been a factor in her ability to stop a motion. Lower extremity strength relates to the ability of the subject to control the range of motion in the lower extremity joints over time. To reduce the force of impact, a large range of motion or linear distance is desirable. If this does not occur during a controlled landing, falling will increase the linear distance and can prevent the skater from being injured.

Joint Range of Motions

Joint range of motion was calculated for shoulder and hip rotation in the transverse plane, thigh angle, knee angle, and trunk inclination from the vertical axis. The ranges of motion are presented in Table 4.

Shoulder and Hip Rotation

Shoulder and hip rotation during landing is expected since the entire body was rotating during flight. If the skater produced angular momentum to make the necessary turns during flight and during landing, but spiraled out of the turns to reduce the impact force, the shoulder and hip rotation would be small. Subject 1 had the smallest range of motions for both shoulder and hip rotation for all three jumps. Her range was smallest for the axel, the easiest of the three jumps, and largest for the double loop, the hardest of the three jumps. Subject 4, the second best jumper, had

Table 4

Average Joint Range of Motion and Position for the Axel, Double Toe Loop, and Double Loop Figure Skating Jumps' Landing Phase

Subject	Jump	Shoulder			Hip			Knee			Thigh/Trunk			Trunk		
		Min	Max	*R*	Min	Max	*R*	Min	Max	*R*	Min	Max	*R*	Min	Max	*R*
1	A	134	173	39	125	156	31	126	155	29	113	156	43	2	15	13
2		23	160	137	27	168	141	131	148	17	119	149	30	7	39	31
3		97	175	78	119	176	57	126	153	27	95	154	59	1	27	26
4		89	173	84	100	170	70	123	156	33	110	164	54	9	36	27
1	DT	120	175	55	111	176	65	129	157	28	107	158	51	1	12	11
2		82	174	92	93	174	81	124	152	28	94	155	61	1	39	38
3		38	164	126	51	167	116	137	164	27	119	165	46	6	31	25
4		80	168	88	102	168	66	114	147	33	110	162	52	2	19	17
1	DL	108	175	67	116	171	55	132	159	27	111	158	47	2	20	18
2		6	105	99	10	131	11	133	162	29	111	159	48	1	27	26
3		78	170	92	84	171	87	118	155	37	108	155	47	2	33	31
4		80	168	88	102	168	66	114	147	33	110	162	52	2	19	17

Note. Units of measure are in degrees, Min = minimum angle, Max = maximum angle, and R = range of motion.

rotations that were about the same for each of the three jumps. Subject 2's and Subjects 3's performances were inconsistent with respect to shoulder and hip rotations. For many of the jumps, these two subjects' ranges of motion were much larger than Subjects 1 and 4. This indicated that Subjects 2 and 3 did not produce a consistent amount of angular momentum to turn. The large angular momentum is another factor that would make landing difficult. The angular momentum and large shoulder and hip rotations would cause torsion stress on landing with the skater continuing to turn like a cork screw. This action could have contributed to Subjects 2 and 3 falling during the Final Landing Phase of the double toe loop and double loop jumps.

Shoulder rotation should be greater than hip rotation. Since the shoulders are farther from the feet at landing, angular momentum would cause a greater rotation. If the shoulder and hip rotations were about the same, the angular momentum would not be great during the landing motion. This could be the case since the subjects in this study performed single axels, single double toe loops, and single double loops. For this reason little difference was seen between shoulder and hip rotation.

The minimum and maximum values reported for shoulder and hip rotation reflect the direction the skater approached the filming area prior to executing the jump. Therefore, these values had little meaning.

Lower Extremity Angles

Lower extremity angles indicated posture at landing. When these angles are optimal, maximum distance to reduce the force of impact occurs. When the human body lands, the initial body position is extension of the trunk and lower and upper extremities. This position places the center of gravity as high as possible at the beginning of the landing phase and causes the largest possible downward vertical displacement of the center of gravity during the landing phase (Kreighbaum & Barthels, 1996). Knee range of motion was similar for Subjects 1, 2, and 4, 110° to 119°, across the three jumps. Range of motion for Subject 1 was smaller, 95°, 94°, and 108°, for the axel, double toe loop and double loop jumps, respectively. Subject 3 was unable to successfully land one of the three double toe loop jumps and all three of the double loop jumps. This small range of motion would contribute to her performance problem.

The thigh/trunk angle and trunk inclination should be examined together. Trunk inclination should be small, indicating the trunk was vertical during the landing. If trunk inclination was large, the subject may have positioned the trunk to increase the moments of inertia and reduce the angular momentum created at takeoff (Hay, 1993). This would be a characteristic of a less skilled performer and very characteristic of a beginner. In this study, Subjects 1 and 4 were more skilled than Subjects 2 and 3. The thigh/trunk angle was related to position of the thigh in relationship to the trunk. The maximum thigh/trunk angle should be high, close to full extension, 180° at the beginning of the Initial Landing Phase. This extended position would provide for a greater vertical displacement of the center of gravity during the landing phase (Kreighbaum & Barthels, 1996). The data for this study showed all subjects were similar across all jumps, 149° to 165°.

Summary of Range of Motions

Differences in shoulder and hip rotations among the subjects were small. The smaller rotations indicated a smaller angular momentum. This could be related to the various masses of the subjects or to better motor control. A skilled performer will create enough angular momentum to accomplish the turning motion compared to an unskilled performer who creates more momentum than required to perform the task. The unskilled performer may create momentum to compensate for a small flight time. The greater momentum would turn the skater faster. However, the landing phase of the jump would be harder to control. This may have caused many of the falls for the subjects in this study. Trunk inclination during landing also supports this conclusion. When trunk inclination is great, the body's moments of inertia are greater and angular velocity will be reduced (Newton's 2nd Law). Subject 2's and Subject 3's trunk inclination was greater during landing than Subject 1. Subject 4's trunk inclination was similar to Subject 1 during the double toe loop and double loop jumps and similar to Subjects 2 and 3 during the axel jump.

CHAPTER V

SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The problem of this investigation was to describe the kinetics and kinematics of three figure skating jumps: (1) single axel, (2) double toe loop, and (3) double loop jumps. Specifically, the researcher investigated impact force, kinetic energy, and selected kinematic variables of female skaters during the landing phase of the three different figure skating jumps. Kinetic energy and impact force were calculated during three phases of landing: Initial, Mid, and Final. Each of these phases represented a third of the time spent in landing each of the three jumps. The kinematic variables measured during the landing phase of the three jumps were: (a) vertical velocity, (b) horizontal velocity, (c) shoulder rotation, (d) hip rotation, (e) thigh/trunk angle, (f) trunk inclination, and (g) knee angle. The purpose of this study was to establish a better understanding of the stresses placed on a skater's body when executing jumps. It was intended that the biomechanical analysis of figure skaters of average to above average ability would provide evidence of the strength training and other types of physical training necessary to assure success in learning jumping skills. Current literature did not address the physical fitness attributes needed to be successful in performing figure skating jumps.

Four subjects from Southwestern Michigan, mean age 22 years, volunteered to serve as subjects for this study. One subject competed in the senior division and the other three subjects competed in the junior division of the United States Skating Association competitive categories. Subjects performed three trials of each jump—axel, double toe loop, and double loop—in a random order. Subjects were required to perform the jumps in a two-meter square area. Two video cameras were positioned so that their focal lengths were perpendicular to each other and intersected in the center of the two-meter square area. Motus, Peak Performance Technologies, Inc., Englewood, CO, software and hardware was used to perform a three-dimensional biomechanical analysis.

Data were averaged across the three trials. Descriptive statistics were used to compare and contrast differences among the jumps and differences among the subjects.

Findings

The most pertinent findings included:

1. The average vertical velocity for each subject decreased as the difficulty of the jumps increased from axel to double toe loop to double loop. Subject 1 maintained relatively consistent average vertical velocities, horizontal resultant velocities, and standard deviations across the jumps. Subjects 2, 3, and 4's velocities were inconsistent across jumps.

2. Subject 1 dissipated her kinetic energy more evenly over the three phases of Landing, Initial, Mid and Final, for each of the jumps compared to the other subjects.

3. Subjects 2, 3, and 4 dissipated most of their kinetic energy during the Initial Phase for the easier jumps (axel and double toe loop) and during the Final Phase for

the hardest jump (double loop). This method of kinetic energy dissipation caused their performance to be poor and resulted in the many falls.

4. Subject 1 distributed the impact force across the phases of landing in a more uniform pattern and thus was better able to control the desired motion.

5. Subjects 2 and 3 fell many times during the Final Phase of landing when executing the difficult jumps, double toe loop and double loop. Their ability to control the force of impact at landing may have been related to lack of strength in the lower extremities and poor technique or a combination of the two.

6. Differences were seen in shoulder rotation, hip rotation, and trunk inclination among the subjects across the jumps.

7. Smaller differences were seen in the thigh/trunk angle and the knee angle among the subjects across the jumps.

Conclusions

The conclusions were:

1. The more practice time and the more experience the skaters had, the more consistent they were in performing the trials.

2. Impact force and kinetic energy were greater for the better jumpers than for the poorer jumpers.

3. The more skilled jumpers experienced a gradual dissipation of impact force and kinetic energy over a greater time when compared to the unskilled jumpers.

4. Similar shoulder and hip rotations were observed in all subjects. However, the better jumpers had a more upright trunk position during landing than the poorer jumpers.

Recommendations

For further study, the following recommendations need to be considered:

1. In future studies, subjects should include a greater range of skill levels, age range, and numbers.

2. Four cameras should be used to capture the motion from four quadrants. This would provide more accurate data and make digitizing easier.

3. The mechanics of single, double, and triple turns should be compared for the axel, double toe loop, and double loop jumps.

4. Biomechanical analyses should include successful jumps and lands as well as unsuccessful jumps and landings.

Appendix A

Screening Questionnaire

Screening Questionnaire

Code: ________________________

What is your current level of skating? ______________________

1. How many hours per week are you presently skating? Consider both practice and competition time.
   _____ 1 to 3 hours
   _____ 4 to 6 hours
   _____ 7 to 10 hours
   _____ More than 10 hours

2. During the past year, which of the following jumps have you practiced on a weekly basis?
   _____ Axel
   _____ Double toe loop
   _____ Double loop

3. During the past year, which of the following jumps have you used in competition?
   _____ Axel
   _____ Double toe loop
   _____ Double loop

4. Other than skating, what other types of conditioning do you engage in weekly, and how much time do you spend in each activity?
   _____ Weight training Time: _____ hours
   _____ Flexibility training Time: _____ hours
   _____ Endurance training Time: _____ hours
   _____ Circuit training Time: _____ hours
   _____ Other (Please list)
   ______________________ Time: _____ hours
   ______________________ Time: _____ hours

5. Have you experienced any of the following medical problems during the past 6 months?
   _____ Lower extremity sprain
   _____ Lower extremity strain
   _____ Fractured bone
   _____ Other orthopedic injuries to the lower extremities (Please list)
   ____
   ____
   _____ Orthopedic injuries to the upper extremities (Please list)
   ____
   ____
   _____ Orthopedic injuries to parts of the body other than the extremities (Please list)
   ____
   ____

6. Are you presently recovering from a cold or flu?
   _____ Yes
   _____ No

7. Have you maintained a regular training regime during the past week?
   _____ Yes
   _____ No

Appendix B

Consent Form

Western Michigan University
Department of Health, Physical Education, and Recreation
Principal Investigator: Dr. Mary L. Dawson
Research Associate: Laura Blazok

I have been invited to participate in a research project entitled "A Biomechanical Analysis of the Kinetics and Kinematics of Three Figure Skating Jumps". This research is intended to examine the impact forces, torques, and posture during the landing phase of the axel, double toe loop, and double loop figuring skating jumps. This projects is Laura Blazok's master's thesis, a part of her degree requirements.

My consent to participate in this thesis project indicates that I will be asked to attend one, 1-hr session with the researchers. I will be asked to meet Laura Blazok in the Lawson Ice Arena at the entrance to the ice. The session will begin with a questionnaire that I will fill out concerning past skating history. If any of the jumps in question number 3 and 4 are not checked, I will not qualify as a participant for this study. Next the researcher will weigh me, weigh my skates, and locate the center of gravity of my skates with a plumb line. Once I am ready to skate, I will be given 10-15 min to warm up using my personal warm up routine that I use before practice and competition. If at the end of 10-15 min, I feel I need more time to warm up I will be allowed to continue my warm up. After I have had sufficient time to warm up, the researcher will orient me by explaining where in the ice arena I will perform the jumps. I will perform each jump five times with a rest period of 2 min between each jump.

As in all research, there may be unforeseen risks to the participant. The risks to the reseach participant in this study include the general risks associated with figure skating such as muscle soreness, muscle sprains and strains, fractured bones, and lacerations. A person trained in first aid will be present during the filming of the jumps. If an emergency arises, appropriate immediate care will be provided and I will be referred to the Sindecuse Health Center. No compensation or treatment will be made available to me except as otherwise specified in this consent form.

I am aware that the current testing may be of no benefit to me. Knowledge of kinetic and kinematic variables associated with landing will provide information concerning the strength and physical characteristics necessary to learn and practice skating jumps. Such information could aid my coach in creating strength and conditioning programs for me and assist in developing training techniques for teaching and practicing the jumps in a safe manner.

All information concerning my participation is confidential. This means that my name will not appear in any document related to this study. The forms will all be coded. Laura Blazok will keep a separate master list with the names of all participants and their code numbers. Once the data are collected and analyzed, the master list will be destroyed. The consent and screening forms, a disk copy of the electronic generated data, and the video tapes will be retained for a minimum of 3 years in a locked file in the principal investigator's laboratory. A second disk copy of the electronic data will be stored by Laura Blazok for a minimum of 3 years.

I may refuse to participate or quit at any time during the study without any effect on my grades or relationship with Western Michigan University or the skating team. If I have any questions or concerns about this study, I may contact either Dr. Mary Dawson at (616) 387-2546 or Laura Blazok at (616) 387-2710. I may also contact the Chair of Human Subjects Review Board at (616) 387-8293 or the Vice President for Research at (616) 387-8928 with any concern that I have. My signature below indicates that I am aware of the purpose and requirements of the study and that I agree to participate.

This consent document has been approved for use for 1 year by the Human Subjects Institutional Review Board (HSIRB) as indicated by the stamped date and signature of the board chair in the upper right hand corner of both pages of this consent form. Subjects should not sign this if the corners do not show a stamped date and signature.

______________________________ ______________

Signature of Participate Date

______________________________ ______________

Signature of Investigator Obtaining Consent Date

Appendix C

Human Subjects Institutional Review Board
Letter of Approval

Human Subjects Institutional Review Board

Kalamazoo, Michigan 49008-3899

WESTERN MICHIGAN UNIVERSITY

Date: 11 January 1999

To: Mary Dawson, Principal Investigator
Laura Blazok, Student Investigator for thesis

From: Sylvia Culp, Chair

Re: HSIRB Project Number 98-12-03

This letter will serve as confirmation that your research project entitled "A Biomechanical Analysis of the Kinetics of Three Figure Skating Jumps" has been **approved** under the **expedited** category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note that you may **only** conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: 11 January 2000

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