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Effects of water ski ramp on sagittal knee flexion

Audrey Sue Lundy

EFFECTS OF WATER SKI RAMP ON SAGITTAL KNEE FLEXION

By

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ABSTRACT

EFFECTS OF WATER SKI RAMP ON SAGITTAL KNEE FLEXION

BY

AUDREY SUE LUNDY

Non-contact ACL injury is common in sports involving cutting and landing maneuvers. Female athletes are predisposed to a 4-6 times greater risk of this injury than are males. Numerous factors influencing this type of injury have been studied, although no single cause has been determined. Water ski jumping involves two landing maneuvers; first upon impacting the ramp and second upon landing on the water after a jump. Female skiers currently use a ramp that is 1.65m high, 6.8m long, at 24.3% grade. Numerous knee injuries have occurred with female skier jumpers since the height of the ramp was raised from 1.5m to 1.65m in 1997. While commonly debated among coaches and athletes, no research has been done on the impact of various ramps heights to the female knee. This investigation examined the mechanics of the knee on each of the ramp heights; specifically, to determine if there was a significant change in knee flexion angle that can be attributed to the ramp height. Results showed that, upon initial impact, there was no significant difference in knee flexion angle between the two ramps ($p > 0.05$). At final impact, knee angle was greater on the 1.65m ramp, although it was not statistically significant ($p > 0.05$). Further research is needed in this area before drawing any conclusions.

Key Words and Phrases: ACL injury, knee flexion angle, water ski jumping.

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Chapter I

MANUSCRIPT TO BE SUBMITTED TO:

Sport Biomechanics

EFFECTS OF WATER SKI RAMP ON SAGITTAL KNEE FLEXION

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INTRODUCTION

. This thesis follows the format prescribed by the APA style manual and the Department of Health, Physical Education and Recreation. The anterior cruciate ligament (ACL) is responsible for the prevention of anterior shifts of the tibia. It joins the distal medial surface of the femur to the proximal, anteromedial surface of the tibia (Johnson, 1995). Non-contact anterior cruciate ligament injury is common in many sports, especially those involving cutting and landing maneuvers. Female athletes have a tendency to be more (4-6 times) predisposed to this type of injury than their male counterparts (Hewett, 2000; Hewett, et al. 2006). Numerous factors contributing to the occurrence of injury have been studied, although no single cause has been determined.

The sport of water ski jumping involves two landing (or contact) maneuvers; the first upon impacting the jump ramp and the second landing on the water after a jump. Due to a recent increase in knee injury occurrence upon landing on the ramp, for the purposes of this study, only that landing will be looked at. Prior to the 1998 ski season, knee injuries in water ski jumping generally occurred when a skier impacted the water after completing a jump. Female skiers currently use a ramp that is 1.65m high and 6.8m long, or 24.3% grade (in the past, females used a 1.5m ramp height, 6.8m long). During anecdotal comments of several professional women ski jumpers, it was revealed that prior to the summer of 1998, when the increased ramp height went into effect, few if any women had knee injuries due to impact on the ramp. Five women, during the 1998 season, suffered from ACL injuries upon contacting the ramp, or due to a landing impact. The jumpers estimated that this number was approximately 40% of the entire pro field, and while it was unclear, the increased ramp height was thought to be the cause of injury in all cases. Regardless of injury, many of the jumpers also noted that they feel the 1.65m ramp allows for greater distance, and gives them a competitive advantage.

The purpose of this study was to examine mechanics of the knee upon impact of the jump ramp at each of the ramp heights. Specifically, to determine if there was a significant change in knee flexion angle and angular acceleration of the knee that can be attributed to the ramp height. It was hypothesized that there will be greater flexion of the knee in the sagittal plane with the 24.3% grade (1.65m) ramp compared to the 22.05% (1.50m) ramp. While commonly debated among coaches and athletes alike, no specific research has been done on the impact of various ramp heights to the knee. Due to the fact that skiers noted an increased incidence of knee injury on the ramp, after the ramp height change went into effect, for this study we chose to examine only the landing on (or contact of) the ramp, in an attempt to find any differences in the kinematics of the knee joint that may be due to the height of the jump ramp.

METHODS

Subjects: Subjects were female water skiers, between the age of 18 and 28, qualified to compete at the international or professional level. Athletes were recruited from Bennett's Water Ski Team (Zachary, La). To be included in the study, each potential subject was required to complete a Physical Activity

Readiness Questionnaire (Par-Q). Informed, written consent was obtained from all subjects prior to participation in this study. Approval for this project has been obtained through the appropriate Human Subjects Research Review Committee #HS06-22.

Experimental design: After informed consent was obtained, height and weight measurements were taken. Subjects were instrumented with horizontal markers encompassing four points on the left leg. Two markers were placed on the lateral aspect of the left thigh, approximately half way between the hip and the knee. Two more were placed on the lateral aspect of the left leg, approximately half way between the knee and the ankle. The markers were placed on the outside of the protective, padded wetsuit worn by each subject in order to be highly visible for the video analysis. Each subject wore her own protective gear, including a padded wetsuit, helmet, and arm sling during the study. Four of the five subjects chose to wear their own knee braces due to prior knee injury. Subjects performed three jumps on each of the ramp heights (1.50m and 1.65m). For all trials the boat was traveling at 51 $km \cdot h^{-1}$. Boat speed was held constant through the use of Perfect Pass Speed Control (Nova Scotia, Canada). Subjects were asked to perform a single wake jump for each of the trials, meaning the starting position for the jump was between just out side the curl of the left boat wake and the right side of the jump ramp. The height of the ramp was changed through an electronic system operated from the shore, after completion of all the trials (3) on one height. The electronic system was calibrated prior to the beginning of data collection to ensure proper height and angle of the jump ramp at each of the ramp heights tested. The order of heights was selected at random, and after completion of trials at one height, the trials for the next height were immediately performed. A practice session in water ski jumping generally lasts six jumps, so this was not an uncommon or excessive work load for the subjects to under go. Subjects rested between jumps for approximately 60 seconds while they skied to the end of the lake to reenter the jump course. To ensure that conditions were as similar as possible between the trials, the same boat, boat driver, boat speed, and ramp was used for all trials by all subjects, to reduce the effects that their variability may have on the data.

Each trial by all subjects was recorded on video. The camera was on the left side of the ramp. Recording of each trial began from just prior to subject contacting the ramp. A 120 Hz JVC GL9500 digital recording device was used to capture each trial. This camera recorded at a speed of 120 frames per second. A rectangular calibration object (52.70cm by 30.50cm) was held in the plane that the skier was crossing on the jump ramp, and was used for scaling purposes during the digitizing process. The camera was placed on shore approximately 30m away from the jump ramp, and was zoomed to cover a viewing area of approximately three meters.

Data Analysis

Each trial was recorded from the point just prior to the subject contacting the ramp, until they left the video field of view, approximately 13 frames in total. Initial impact, for the purposes of this study, was considered to be the point when the subject’s ski contacted the jump ramp. Final impact was defined as the first point when the subject's entire ski was on the jump ramp. Through digitization of the videos of the trials, the markers placed on the subjects were used to determine the degree of movement of the knee joint upon impacting the ramp, as well as angular acceleration. In the sagittal plane, flexion angle of the left knee and angular acceleration were calculated using *PEAK MOTUS 8.5* (Centennial, CO**)** to determine these movements at both the initial and final impact point. A second order Butterworth filter with a 5Hz cutoff was used during data analysis.

Statistical Analysis

Statistical means and standard deviation were calculated for each variable and each subject. A two-way, repeated measure ANOVA (ramp height x trial) was used to compare knee flexion values and angular acceleration at each ramp height. All six trials were used for statistical analysis. The SPSS statistical package (*SPSS for Windows*, version 13.0, Chicago, IL) was used to conduct all statistical analyses with an alpha level of $P < 0.05$ to determine significance.

Results

Means and standard deviations for knee angle at the points of initial and final impact upon each of the ramp heights are listed in table 1. A two-way repeated measures ANOVA was calculated comparing trials by ramp height (1.5m and 1.65m). Subjects showed no significant difference in knee flexion angle between the 1.5m and 1.65m ramp trials ($F(2,8)= 0.725$, $p= 0.514$) upon initial impact of the ramp. Initial knee angle was considered to be the point when the subject's ski first contacted the jump ramp. No main effect was found for initial impact trials ($F(2,8)=0.264$, $p= 0.774$) or for the ramp height ($F(1,4)= 1.209$, $p= 0.333$). Final knee angle was described as the first point when the entire water ski was on the ramp. There was no significant interaction of trials by ramp height (1.5m and 1.65m) for the final knee angle ($F(2,8) = 0.594$, $p = 0.575$). There was a significant difference between the trials for final knee angle ($F(2,8) = 11.189$, $p = 0.005$). The analysis revealed no main effect for the final impact trials ($F(2,8) = 11.189$, p= 0;005) or for ramp height ($F(1,4) = 0.534$, $p = 0.505$).

Means and standard deviations for knee joint angular acceleration are listed in table 2. Angular acceleration was calculated using a repeated measure ANOVA (trial*ramp height). The analysis revealed no main effect for initial impact trials (F(2,8)=3.483), p=0.082), or for ramp height ($F(1,4) = 0.053$, $p = 0.830$). There was no main effect for final angular acceleration trials ($F(2,8) = 0.504$, $p = 0.622$) or ramp height ($F(1,4) = 0.491$, $p = 0.109$). No interaction was found for angular acceleration (ramp*trial) at initial impact ($F(2,8) = 3.116$, $p = 0.100$) or at final impact ($F(2,8) = 0.989$, $p = 0.413$).

Table 1. Knee angle (degrees) for water ski jumpers (n=5) initial and final contact on ramp.

Ramp	Trial	Initial Knee Angle (Mean, SD)	Final Knee Angle (Mean, SD)
1.5m	1	145.84 ±5.26	144.70 ±6.44
1.5m	2	147.70 ±5.80	142.92 ±2.91
1.5m	3	143.80 ±6.64	135.60 ±5.11
1.65m	1	147.80 ±7.11	140.50 ±6.40
1.65m	2	146.50 ±7.52	144.30 ±4.70
1.65m	3	147.71 ±5.90	146.10 ±7.00

Table 2. Angular Acceleration (degrees · s^{-1}) for water ski jumpers (n=5) initial and final contact on ramp.

Ramp	Trial	Initial (Mean, SD)	Final (Mean, SD)
1.5m	1	32,387.90 ± 70,245.36	9,112.73 ±108,077.81
1.5m	2	76,563.80 ± 137,032.70	18,493.04 ± 57,629.90
1.5m	3	-56,927.40 ± 50,974.07	-38,269.51 ± 60,762.61

1.65m	1	-25,016.77 ± 24,085.82	26,995.94 ± 71,258.70
1.65m	2	-6,577.26 ± 36,109.24	-2,209.14 ± 20,866.80
1.65m	3	-63,346.94 ± 85,044.84	-23,266.54 ± 61,218.40

Discussion

This study is the first to examine the potential effect of ramp height variation on knee angle during a landing action (contact). Many authors have examined the mechanics of the female knee during landing moments (Gerritsen, 1996; Ford, 2003; Kernozek, 2005; Yu, 2006), although none of this research has been applied to the sport of water ski jumping. The current study examined only the sagittal plane mechanics of knee joint angle and angular acceleration. There were no significant differences found in knee flexion angle and angular acceleration of the knee joint at initial and final impact between the 1.5m and 1.65m ramp heights. Initial impact, was defined as "the point when the entire foot, not necessarily the ski, was visible on the jump ramp."

Previous research by Yu et al. (2006) reported that during jump-stop landings females had a tendency to land with decreased knee flexion, when compared to male subjects, which could potentially lead to increased injury of the ACL. Similarly, Boden and colleagues (2000) stated that most ACL injuries occurred during foot strike when the knee was near full extension. Hewett et al. (2006) concurred with these findings, reporting that knee injuries commonly occur with the knee positioned within 20-30 degrees of full extension. Upon initial impact with the jump ramp, the mean knee angle was 145.76 degrees (1.5m) and 147.30 degrees (1.65m). These findings, especially on the 1.65m ramp, are close to the 20-30 degree critical zone that Hewett et al. (2006) has identified, making the position a potentially dangerous one to hit the ramp in.

There was no significant difference found in the knee flexion angle between the two ramp heights tested, at the point of initial impact. This is an interesting finding, because it shows that the subjects are not adjusting their body position in preparation for landing on one ramp height or the other.

In the current study, there was significant difference found between the trials for the final impact data, and while it was a minor difference taking place, it shows that the skier is not in the same position every time, after hitting the ramp. It could be speculated that these acute differences could potentially cause injury, at some point.

It has been shown by previous research that injury risk for females includes the frontal plane movement as well. Ford, et al. (2003) noted that females consistently demonstrated greater total knee valgus motion and greater maximum valgus knee angle during landing moments, a position which increases the risk of knee injury. When attempting to land with the knee near full extension and the tibia rotated externally, valgus collapse is likely to occur (Kernozek, 2005). Therefore, frontal as well as sagittal plane motion warrants further investigation in relationship to landing mechanisms of water skiers on the jump ramp.

At the elite level of water ski jumping, for competition, skiers typically perform a double wake cut, as opposed to the single wake cut that was used for this study. A double wake cut is performed by the skier starting on the left hand side of the boat (the same side the ramp is on) and cutting out as far as possible to the right side of the boat. The double wake cut is used by the skier to generate more speed coming into the ramp, which, generally equates to a greater distance jumped. For ease of data collection the current study used the single wake cut, where the skier starts on the left side of the boat, (same side of the boat that the ramp is on) and takes only one cut directly over the ramp. This was done to ensure all subjects were doing essentially the same thing. Also, data collection for this study was done extremely early in the ski season for all the subjects involved. At that time, they had not progressed in their training to the point where they were taking jumps similar to those in competition. The differences in knee angle between the two ramp heights would likely be more evident if a double cut jump was analyzed, due to the increased speed the skier would be traveling at when contacting the jump ramp.

One male subject was also examined during this project. While his data was not analyzed to the degree of the female subjects, preliminary results showed that he approached and initially impacted the ramp with greater knee flexion than did the female subjects. Further research is needed in this area to distinguish if there are gender differences in water ski jumping.

While a significant difference was not found between the trials on the two ramp heights, had the study used a greater number of subjects, there is the possibility that a significant difference would have been found. However, the effect size for knee flexion angle and angular acceleration at both the initial and final impact points was small, between 0.1 and 0.4 for all cases. The observed power was likewise very small, due to the small sample size. Through out the world, there are less than 50 elite, international, female water ski jumpers. While the number of subjects was small (n=5), it did represent approximately 10% of the entire population world wide. Results did show that, although not significant, subjects impacted the 1.65m ramp with decreased knee angle compared to the 1.5m ramp. Since this area of research has been virtually untouched until the present study, further research is warranted to determine the effects of the ramp height variations on the mechanics of the knee.

Conclusion

With the scope and limitations of the current study, the following conclusions were drawn: 1) with regards to initial impact; there were no significant differences between the 1.5m trials and the 1.65m trials. 2) Although there was a trend toward decreased knee flexion angle upon the 1.65m jump ramp during the final impact phase, there was no significance difference shown. Future research in the area is needed to investigate the mechanics of the knee in the frontal plane, as well as comparing gender differences in the biomechanics of the knee during water ski jumping.

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CHAPTER II
LITERATURE REVIEW

INTRODUCTION

There has been minimal research done on the sport of water skiing, with the majority focused on injury mechanisms of recreational skiers. Water ski jumping is a relatively non-existent area of research that currently involves two different landing moments, one on the ramp and the other on the water following a jump. Water ski jumping shares some similar aspects to the mechanics of snow skiing, so therefore, the literature review for this topic will discuss the injury mechanisms of waterskiing, general knee injury mechanisms, landing differences between gender, and snow ski injury mechanisms.

WATER SKI RESEARCH

In two separate studies Sallay et. al., (1996) and Blaiser, (1990) investigated the common hamstring injury occurring in novice water skiers. During the submerged starting phase, improper body position (involving extended knees), forces the tips of the ski below the surface of the water. This deceleration of the lower body, combined with the continued forward momentum on the upper body from the tow boat, resulted in extreme flexion of the hips. Sallay and colleagues (1996) also mention one subject's injury occurred while landing off a ski jump, causing the same knee extension and lower body acceleration followed by the extreme hip flexion due to the momentum of the upper body.

Eberhart, (1988) examined different phases associated with the slalom turn and muscles involved with maintaining proper position during each phase. The deceleration phase occurs after crossing the second boat wake, when the ski begins to slow down, in anticipation of turning. The quadriceps, gluteus maximus, latissmus dorsi, biceps and fore arm flexor muscles are isometrically contracting to hold the body in an erect position, with knees and ankles bent. Shoulders are square to the shoreline for the deceleration phase, and arms are flexed, holding the handle close to the hip (Eberhart, 1988). Proper body position in this phase, allows the skier to transition into the turn with ease. At the end of the deceleration phase, the momentum gained from crossing the wakes is used to roll the ski on to the inside edge, while continuing to move away from the buoy.

The second phase, the reach, occurs as the skier extends the inside arm toward the direction of the pull of the boat, while maintaining the same erect positioning of the first phase. It is crucial during the reach for the skier to keep the shoulders and head level. The rectus abdominus, neck extensors, gluteus maximus, gasttrocnemious, and quadriceps are isometrically contracted to stabilize the body, while the latisimus dorsi, pectoral muscles, and the forearm flexors are contracted eccentrically to extend the arm (Eberhart, 1988).

The final phase, the acceleration phase, requires two movements. The first, concentrically drawing in of the handle to the outside hip, activates the latisimus dorsi, biceps, and fore arm flexors. The outside arm must be positioned to re-grasp the handle, with the elbow lifted to approximately hip joint and the hand near the outside hip. This also allows for balancing of the body during this dynamic movement. The second part to this phase occurs when the outside arm begins to slightly adduct across the body to meet the handle. This motion is crucial because it positions the shoulders to face across the wake, thus setting up for acceleration to the other side of the boat. This position uses the latisimus dorsi, trapezius, deltoid, biceps, and forearm extensors to pull the handle in, while the back extensors, rhomboids, and trapezius contract to keep the back, chest and shoulders erect. The lower extremity muscles, specifically the gluteus maximus, hamstrings, quadriceps and calf are contracted isometrically to maintain the lower body position of ankle dorsiflexion, and knee and hip flexion (Eberhart, 1988). Conclusions from Eberhart's research lead to recommendations for in season and off season strength and conditioning program for slalom skiers. It places emphasis on total body muscular endurance as well as cardiovascular conditioning.

Leggett et al., (1996) investigated various physiological factors of water skiers and proper body position during water ski jumping. The desired body position for skiers approaching the jump ramp involved isometric contraction of the lower extremity muscles including the quadriceps, hamstrings, and gluteus maximus, while knees and ankles are bent, pushing forward. With the exception of Leggett no other research to date has been conducted specifically on water ski jumping, and the Leggett et al.(1996) study did not investigate what happens when the skier contacts the jump ramp.

ANTERIOR CRUCIATE LIGAMENT INJURY MECHANISMS AND RISK FACTORS

Rupture of the anterior cruciate ligament (ACL) occurs when there is excess anterior tibial translation or during rotation of the femur on the tibia (Kirkendall & Garrett, 2000). During landing or stopping moments, extension of the knee, combined with quadriceps activation that is not counter balanced by hamstring activation, can enable anterior tibial translation, placing extreme force on the ACL. Both intrinsic and extrinsic factors have been identified as contributing to female ACL injury, including variation in quadriceps angle, pelvic width, hormonal levels, muscular strength, neuromuscular control, landing mechanisms and postural control (Hewett, 1999; Hewett, 2000; Krikendall & Garrett, 2000).

Compared to males, females have a wider pelvis, creating a greater quadriceps angle. The quadriceps angle (Q angle) is the angle of the line between the anterior superior iliac spine and the mid point of the patella, and the line between the tibial tubercale and the same point on the patella. Normal values range from 8 to 17 degrees, and many females have greater Q angles than men. Larger Q angle in females is thought by some to be caused by the wider pelvis and shorter femoral length than that of their male counterparts (Boden, 2000; Huston, 2000). This difference in alignment, combined with external tibial torsion and femoral anterior torsion, places greater strain on the female knee joint, increasing the chance of injury (Traina & Bromberg, 1997; Toth & Cordasco, 2001).

The size of the intercondylar notch that houses the ACL has also been identified as a risk factor for injury to the ligament. Griffin, et al. (2006) in a recent review reports that numerous studies have found that a small, narrow notch leads to an increased risk of ACL injury. Ireland (2002) had similar findings, and went on to state that smaller notches, generally house smaller anterior cruciate ligaments, but it currently is unknown whether a smaller ligament is weaker than a bigger one. Hewett, and colleagues (2006) state that a narrower notch could result in increased elongation of the ACL when it is placed under high degrees of tension. It was also noted in the study that a small notch is a risk factor in both genders, not just females, although small notch width is more commonly found in females (Hewett, et al., 2006). In contrast, Huston and coauthors (2000) state that numerous studies report that there is no correlation between anterior cruciate ligament injury and notch width, and therefore recommends that intercondylar notch measurements should not be used to predict injury potential. Toth and Cordasco (2001) concur with these findings, stating that in the studies measuring the size of the ACL compared with the width of the intercondylar notch contain too much variability to conclude anything definite.

It has been suggested that because females have less muscle mass in the hamstrings and quadriceps than males, and greater joint laxity, that they depend more on the cruciate ligaments for function than males do (Hutchinson, 1995). In addition to this, female athletes tend to enter competitive athletics with only minimal conditioning of what muscle mass they do have (Hutchinson, 1995). Increased physical demands of competitive sports, compared to those of the novice, combined with decreased baseline conditioning, have been documented as risk factors for increased injury of the female knee. Hewett et al. (1999) reported that female athletes who did not undergo neuromuscular training were 3.6 times more likely to injure their knee than those athletes who were trained. Consequently, proper training programs and adequate conditioning not only reduce the injury risk, but improve performances (Hutchinson, 1995).

Hormonal levels in females compared to males have surfaced as another risk factor in anterior cruciate ligament injury, although conflicting research results prevent conclusions from being drawn at this time. Since the discovery of receptor sites in human ACL cells for estrogen and progesterone, it has been hypothesized that sex hormones influence the mechanical properties of the ACL, but this area warrants further research in order to determine the exact mechanism occurring (Griffin, et al. 2000).

According to Hewett (2000), “Female sex hormones (i.e. estrogen, progesterone and relaxin) fluctuate radically during the menstrual cycle and are reported to increase ligamentous laxity and decrease neuromuscular performance and, thus, are a possible cause of decreases in both passive and active knee stability in female athletes” (p.313). Consequently, Pollard, Braun and Hamill (2006), found no significant fluctuations in knee laxity through out the menstrual cycle. The authors did observe that female subjects had greater knee laxity than did male subjects, during pre and post exercise, but a correlation between menstrual cycle and knee laxity was not found. It has been hypothesized that as the levels of estrogen rise, so do the levels of the hormone relaxin (Ireland, 2004). Best known for promoting ligament relaxation in the pelvic area during child birth, increased levels of relaxin could also affect other ligaments of the body, including the ACL (Traina & Bromberg, 1997). Although several different studies have been conducted in an attempt to link the occurrence of ACL injury to various phases in the menstrual cycle, the relationship remains unclear at this time.

LANDING MECHANISMS

Kernozek, (2005) investigated variations in landing between genders. Female athletes were noted to utilize different landing mechanisms than males, and in doing so place the knee in an unfavorable position, with more force on the ACL. In comparing landing differences between genders, the authors also concluded that females contact the ground in a more erect position than males and that they have greater tendency to experience valgus knee moments upon landing. These adaptations can place up to six times more stress on the knee joint and ACL, when positioned only 5 degrees from neutral (Kernozek, 2005). ACL injuries commonly occur when the knee is positioned between 20-30 degrees of flexion and full extension (Hewett, 2006). Similarly, Boden et al., (2000) concluded that the majority of ACL injuries occurred during foot strike, with the knee near full extension.

Ford et al., (2003) suggest that a female’s tendency to land with greater total knee valgus motion and a greater maximum valgus knee angle imply decreased joint stability during dynamic movement, which increases the incidence of injury. Valgus collapse occurs following deceleration, when attempting to land with the knee near full extension, the tibia externally rotated, and the foot planted (Kernozek, 2005).

Yu et al., (2006) reported that during landing in a stop-jump task, females consistently landed with decreased hip and knee flexion angles during initial foot contact, compared to their male counterparts. This occurred despite the fact that the angular velocities of the hip and knee joints at initial contact have a greater effect on ground reaction forces than the position of the knee alone. Yu et al., (2006) also found that at initial ground contact, hip joint motion mainly affected the ground reaction forces in the anterior and posterior direction, while the knee joint motion mainly affected the vertical ground reaction forces.

Boden and coauthors, (2000) in a video review of non- contact mechanisms, confirmed that most ACL injuries occur when attempting a deceleration or landing maneuver, with the knee near full extension. This position allows for maximum eccentric muscle force from the quadriceps, and places strain on the ACL.

Snow Skiing Injury Mechanisms

Similar to snow skiing, water ski jumping requires a great deal of dynamic balance. Water skiers routinely travel and hit the jump ramp at speeds in excess of the 54 $K \cdot h^{-1}$ that the boat is traveling (some skiers and coaches noted the speed was probably 1.5x that of the boat). This is due to the fact that the jumper swings out to the far right side of the boat during a double cut maneuver, before cutting to the jump ramp, generating more speed. The skis in both situations act as levers, and if the body is moving forward or backward relative to the skis, the knee is placed in an unfavorable position, increasing amount of force placed on the ACL, and increasing the risk for ACL injury. When the body is moving forward relative to the skis, hyperextension and anterior bending occur at the knee, often resulting in a force too great for the ligaments of the knee, including the ACL to withstand (Johnson, 1995).

In a study using computer simulation to mimic landing movement during downhill skiing, Gerritsen, et al. (1996) concluded that when the skier was positioned backwards, relative to the skis during landing, the resultant sheer force at the knee joint, and ACL was significantly greater than that of a normal landing. The peak ACL force during the landing was estimated to be 1350 N, which, according to the authors, is believed to be close to failure loads for the ligament. Although the surfaces are different between snow skiing and water ski jumping, and water skiers are towed by a rope, rather than being accelerated down a mountain by gravity, it is not uncommon for a water ski jumper to hit the ramp in a less than ideal position. Skiers noted that often times, this position places the water ski jumpers center of gravity behind the knee joint, similar to the positioning described by Gerritsen, et al. (1996).

In summary, due to the anatomical factors that predispose female athletes to ACL injury (Ireland, 2002; Hewett, 2005) the force placed on the knee during skiing, jumping and landing activity (Johnson, 1995; Yu, et al. 2000; Boden, et al. 2006), it is thought that there will be greater movement of the knee and hip joints when water ski jumping on the higher (1.65m) ramp. The research from Yu et al.

(2000), comparing gender differences during landing moments, noted that females tend to have less knee flexion than do males during this movement. This could have interesting implications for water ski jumpers and additional research in the area should be done. Similarly, the fact that Boden and coworkers (2006) suggested that knee injuries often occur upon landing moments with the knee positioned near full extension implies that this phenomenon should be investigated with regards to water ski jumping as well. Finally, frontal plane biomechanics of the lower extremity, especially varus and valgus moments during landing potentially could effect the risk of knee injury and should be investigated with regards to water ski jumpers (Kernozek, 2005).

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Chapter III

Conclusions and Recommendations

I. Summary and Conclusions

The purpose of this investigation was to determine if there was a significant difference in knee flexion angle upon impacting different jump ramp heights during water ski jumping. Five (5) elite, female water ski athletes, who were qualified for international competition, were filmed while jumping on two (2) different jump ramp heights, 1.5m and 1.65m. The video was digitized and data analysis focused on two specific points: initial impact on the jump ramp, which was defined as the frame when the foot first made contact with the jump, and final impact, defined as the frame when the entire water ski was in contact with the jump ramp. There was no significant difference found between the knee flexion angle or the angular acceleration of the knee joint during initial contact on the 1.5m and 1.65m ramps. Knee flexion angle as well as angular acceleration for the final contact point was not significantly different between the 1.5m and 1.65m ramp heights either. The subject number (n=5) was a limitation of the current study, but since the total worldwide population of elite female water ski jumpers is approximately 50, this represented 10% of the available subjects. There has been no prior research in this area, and the current study was the first of its kind, to investigate the effects of different ramp heights on knee flexion angle of water ski jumpers. In conclusion, there was no difference in the sagittal plane mechanics of the knee joint between the 1.5m and 1.65m ramps.

II. Recommendations for Future Research

The area of water ski jumping warrants further investigation in the following areas.

1. Gender differences and comparisons. While this study only briefly examined one male jumper, that subject did appear to be different than all the female skiers. The differences between gender in mechanics of the lower extremity upon landing on the ramp and on the water should be studied.
2. Female skiers performing a complete double cut to the jump ramp at the required competition speed ($54\ K \cdot h^{-1}$) may better exemplify the differences in biomechanics of the knee during the landing moment on the jump ramp.
3. Frontal plane biomechanics of female water ski jumpers, including varus and valgus moments while landing may be a factor in recent injuries to the knee and can be investigated.

The current study was the first one to look at the water ski jump ramp and its effect on the mechanics of the knee. Even though no significant differences were found through this investigation, the entire sport of water ski jumping warrants further investigation to better define the mechanism of injury common to the sport and to work towards preventing those injuries and maximizing performance as well.

APPENDIX

NORTHERN MICHIGAN UNIVERSITY
DEPARTMENT OF HPER

CONSENT TO ACT AS A HUMAN SUBJECT

Subject Name (print):_____________________________ Date __________

1. I hereby volunteer to participate as a subject in exercise testing. I understand that this testing is part of a study entitled: "Biomechanics of the knee during water ski jumping." The purpose of the study is to investigate the biomechanics of the knee upon impacting the jump ramp.

   I hereby authorize Audrey Lundy to perform on me the following procedures:

   (a) To have me water ski jump on two separate ramp heights (1.5m and 1.65m). I will perform three single wake jumps at each ramp height, for a total of six jumps.

   (b) During all 6 jumps I will be video taped to determine the movement of my knee joint when I hit the ramp. Reflective markers will be placed on my knee, ankle and hip joints.

   (c) To take skin fold measurements, where a small area of my skin will be pinched and measured for thickness at the thigh, tricep, hip, abdominal, armpit, chest, and back.

   (d) To measure the length of my leg, the angle of my knee to my hip, my height and weight.

2. The procedures outlined in paragraph 1 [above] have been explained to me.

3. I understand that the procedures described in paragraph 1 (above) involve the following risks and discomforts: temporary muscle pain and soreness is possible. There is also a possibility of falling while water ski jumping, however, I will wear a padded suit and helmet for protection during all trials. I understand that I can terminate any test at any time at my discretion.

4. I have been advised that the following benefits will be derived from my participation in this study: aside from the educational benefit of learning

about the biomechanics of the knee during water ski jumping, there are no direct benefits to me.

5. I understand that Audrey Lundy will answer any inquiries that I may have at any time concerning these procedures and/or investigations.

6. I understand that all data, concerning myself will be kept confidential and available only upon my written request. I further understand that in the event of publication, no association will be made between the reported data and myself.

7. I understand that there is no monetary compensation for my participation in this study.

8. I understand that in the event of physical injury directly resulting from participation, compensation cannot be provided.

9. I understand that I may terminate participation in this study at any time without prejudice to future care or any possible reimbursement of expenses, compensation, or employment status.

10. I understand that if I have any further questions regarding my rights as a participant in a research project I may contact Dr. Cynthia Prosen of the Human Subjects Research Review Committee of Northern Michigan University (906-227-2300) cprosen@nmu.edu . Any questions I have regarding the nature of this research project will be answered by Audrey Lundy (906-282-6779) alundy@nmu.edu or Thesis Advisor, Randy Jensen (906-227-1184) rajensen@nmu.edu

Subject's Signature:____

Witness:____ Date:_________