THE EFFECT OF INJURY PREVENTION TRAINING PROGRAMS ON ANTERIOR

CRUCIATE LIGAMENT INJURIES IN TEAM SPORT ATHLETES

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Objective: We sought to conduct a meta-analysis to determine whether neuromuscular training programs are effective at reducing anterior cruciate ligament (ACL) injuries. A secondary purpose was to identify and describe some common barriers to implementation for these training programs.

Data Sources: We used the keywords õanterior cruciate ligament,ö õinjury,ö and õpreventionö to conduct a search of Medline and the Cochrane library. A secondary search was conducted on article references lists.

Study Selection: Criteria for inclusion required that studies: 1) evaluate a neuromuscular training program for sports injury prevention, 2) report ACL injury as an outcome measure, 3) investigate team-sport athletes, 4) be prospective and include a control group, and 5) report the number of non-contact ACL injuries. Fifteen studies qualified for inclusion.

Data Extraction: The following data were utilized in the meta-analysis: Number of participants in the intervention group and control group, total number of ACL injuries in the intervention group and control group, and number of noncontact ACL injuries in the intervention group and control group.

Data Synthesis: Eight of the 15 identified studies reported non-contact ACL injuries separately from contact injuries and were included in the primary meta-analysis. We found that neuromuscular training programs were effective at reducing ACL injuries in the population evaluated (RR = 0.30 [95% CI 0.19 to 0.47]). Effectiveness of neuromuscular training programs was also indicated by a sensitivity analysis of all the studies (risk ratio = 0.41 [95% CI 0.27 to 0.63]) and only the randomized controlled trials (risk ratio = 0.52 [95% CI 0.34 to 0.80.])

Conclusions: Our meta-analysis showed that neuromuscular training programs are effective for preventing ACL injuries in team sport athletes. In addition, we identified five barriers to implementation of ACL injury prevention programs (i.e., motivation, time requirements, skill requirements for program facilitators, compliance, and cost), and provided suggestions to reduce these barriers.

The Effect of Injury Prevention Training Programs on Anterior Cruciate Ligament

Injuries in Team Sport Athletes

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Chapter 1: Introduction

Sports-related injuries can detrimentally affect quality of life for individuals who sustain them (Maffuli et al., 2010). Injuries to the anterior cruciate ligament (ACL) are a common and costly type of sports injury (Hewett et al., 2006, part 2; Shultz et al., 2010). It has been estimated that 80,000 people in the United States tear an ACL each year, with over half of these injuries being surgically repaired (Griffin et al., 2000). One of the overarching goals of Healthy People 2020 is to õAttain high-quality, longer lives free of preventable disease, disability, injury, and premature death.ö (USDHHS, 2012). Therefore, prevention of sports injuries can be viewed as an important public health goal.

ACL injuries can be burdensome to individuals who experience them, as well as to society in general. As a serious injury with a long rehabilitation, ACL injuries can cause emotional distress (Morrey et al., 1999) and can hinder academic and athletic achievement (Freedman et al., 1998; Hewett et al., 2006, part 1). Furthermore, the cost of surgery and rehabilitation for the injuries, which has been estimated at $2 billion per year (Gottlob et al.,1999; Wojtys & Brower, 2010), is problematic because it contributes to high health care costs. However, probably the most dire consequence of ACL tears is the fact that the injuries can have a negative impact on future health of individuals who sustain them, especially because they can contribute to early-onset osteoarthritis of the knee (Hewett et al., 2006, part 1; Lohmander et al., 2007). Therefore, because the burden of sustaining an ACL injury is extensive and multifaceted, reducing the number of these injuries that occur would benefit both athletes as individuals and society as a whole.

ACL injuries are most common in sports that involve decelerating, pivoting, and jumping (Griffin et al., 2000; Micheo et al., 2010). A *contact* ACL injury is caused by direct contact

between two athletes or an athlete's knee and an object (Griffin et al., 2000). A *non-contact* ACL injury does not involve contact between players (Hewett et al., 2006, part 1), and is thought to result from the way in which an athlete loads the affected limb or from a loss in balance which creates potentially-harmful forces on the affected knee (Shimokochi & Shultz, 2008). Researchers have reported that 50-80% of ACL injuries are non-contact injuries (Myklebust et al., 1998; Boden et al., 2000; Donnelly et al., 2012). Further, it has been established that ACL injuries occur more often in female athletes when compared to male athletes that play the same sports (Hutchinson & Ireland, 1995; Myklebust et al., 1998; Hewett et al., part 1, 2006), which is why to date, most research has focused on risk factors and prevention in the female population (Hewett et al., 1999; Gilchrist et al., 2008; Kiani et al., 2010). However, the injuries do occur in males, as well (Hewett et al., 1999; Olsen et al., 2005), so the injury prevention programs should be targeted to athletes of both sexes.

Injury Prevention Training Programs

Due to lack of understanding about which mode of training is most effective for prevention, ACL injury prevention programs are often multi-modal. Strength training, agility training, jump training, and balance training have collectively shown some effectiveness in reducing ACL injuries (Caraffa et al., 1996; Mandelbaum et al., 2005; Gilchrist et al., 2008; LaBella et al., 2011). These kinds of exercise programs for injury prevention and performance improvement are often called neuromuscular training programs. The programs are designed to have an effect on how the body moves and to ingrain in a person movement patterns that are more efficient and less injurious. The effectiveness of neuromuscular training programs and how they work is still under investigation with varied results. These studies, published in peer-reviewed journals, provide valuable insight on specific aspects of the injury prevention

programs, including effectiveness of various study designs, types of exercises, program leadership (e.g., coaches or health care specialists), method of teaching the exercises, and duration of training. However, many of the studies have some limitations; specifically: Low sample sizes, non-randomized designs, participant compliance problems, and lack of differentiation between contact and non-contact injuries. Researchers have hypothesized that neuromuscular training programs may alter factors such as muscle strength and activation imbalances, poorly-controlled forward motion of the tibia during deceleration, alignment issues of the foot, ankle, knee, and hip, medial collapse of the knee, and landing from a jump with knees at close to full extension which are thought to have a role in sports-related ACL injuries (Hutchinson & Ireland, 1995; Boden et al., 2000; Hewett et al., 2006, part 1).

Meta-Analyses of ACL Injury Prevention Programs

A meta-analysis can be a helpful tool for comparing and summarizing the outcomes of a number of studies (Deeks et al., 2008). Three meta-analyses of ACL injury prevention training programs already exist. Sadoghi et al. (2012) analyzed 8 studies of training programs, Yoo et al. (2010) analyzed 7 studies, and Hewett et al. (2006, part 2) analyzed 6 studies. All the authors of these meta-analyses concluded that neuromuscular training programs showed some effectiveness for injury prevention. Hewett et al. (2006, part 2) found an odds ratio of 0.40 (95% CI 0.26 to 0.61), Yoo et al. (2010) found an odds ratio of 0.40 (95% CI 0.27 to 0.60), and Sadoghi et al. (2012) found a risk ratio of .038 (95% CI 0.20 to 0.72). However, these meta-analyses did not include several studies on ACL injury prevention programs that are now available (i.e., Olsen et al., 2005; Pasanen et al., 2008; Steffen et al., 2008; Kiani et al., 2010; LaBella et al., 2010; and Walden et al., 2012). In addition, two of the meta-analysis authors (Hewett et al., 2006 and Yoo et al., 2010) did not indicate why they excluded studies from their analyses. Further, while the

summary statistics of these meta-analyses show that ACL injury prevention programs are beneficial in reducing the number of ACL injuries, the authors did not address the issue of barriers to implementation for the training programs. Therefore, it would be beneficial to conduct a more complete meta-analysis on these injury prevention programs and to discuss potential barriers to broader implementation of such programs.

Purpose and Hypotheses

The primary purpose of this study was to determine whether neuromuscular training programs are effective at reducing ACL injuries. A secondary purpose was to identify and describe potential barriers to implementation for these training programs. Due to the fact that ACL tears carry long-term health and financial burdens, there is a need to better understand both the effectiveness of preventive programs and the obstacles that are hindering the widespread use of these programs. We hypothesized that: 1) neuromuscular training programs will be effective at reducing ACL injuries, and 2) that there are barriers to implementation of the programs which may be able to be addressed once identified.

Research Questions

1. Are neuromuscular training programs effective at reducing ACL injuries?
2. What are the barriers to implementation of these training programs?

Operational Definitions

1. ACL injury ó a tear of the anterior cruciate ligament.
2. Neuromuscular training program ó a program of physical exercises that affects body movement patterns.
3. Barrier to implementation ó an obstacle to distributing and utilizing an intervention.

4. Heterogeneity ó variability in participants, intervention characteristics, study designs, or intervention effects among studies in a systematic review (Deeks, et al., 2008).

5. Randomized controlled trial (RCT) ó an experimental research design in which participants are assigned by chance to the control group or the experimental groups. Random assignment is considered the best method of controlling bias in studies. (Crosby, DiClemente & Salazar, 2006)

Methods

Studies of ACL injury prevention programs will be identified from a thorough literature search. A meta-analysis will be conducted to evaluate the effectiveness of the training programs. Potential barriers to implementation in the preventive programs will be identified, and suggestions offered on how those barriers might be overcome.

Limitations and Delimitations

Delimitations

1. Only prospective studies of prevention programs in team sport athletes will be included.

2. Only studies that have ACL injuries as an outcome measure will be included.

3. Only studies published in peer-reviewed journals will be included.

4. Only studies that differentiate between contact and non-contact injuries will be included.

Limitations

1. The study results may not be generalizable to other populations.

2. Some useful, valid studies may be omitted because they do not use ACL injuries as an outcome measure, do not differentiate between contact and non-contact injuries, or were not published in English.

3. Some bias may occur since unpublished studies will be excluded.

Chapter 2: Review of Literature

The purpose of this thesis is to conduct a meta-analysis of the peer-reviewed literature to assess whether neuromuscular training programs for anterior cruciate ligament (ACL) injury prevention are effective, as well as to discuss some potential barriers to implementation of these programs. Given the purpose of the thesis, this literature review will describe the burden of ACL injuries, identify risks for sports-related ACL injuries, examine studies which have analyzed injury reduction training programs, and discuss existing meta-analyses on this subject.

The Burden of Anterior Cruciate Ligament Injuries

The anterior cruciate ligament (ACL) is a key support structure at the front of the knee which connects the femur to the tibia. The ACL helps prevent excessive forward motion in the knee and helps keep the knee from hyperextending (Behnke, 2006). In the United States, the number of ACL injuries has been estimated at 80,000 per year (Griffin et al., 2000). Treatment of ACL tears usually involves a surgical reconstruction of the ligament using a graft. However, repairing the ACL does not return the knee to its original condition before the injury. ACL injuries can have adverse effects on an individual's life, both during the rehab period (Hewett, Lindenfeld, Roccobene, & Noyes, 1999) and in the future, as ACL ruptures are associated with early development of knee osteoarthritis (Lohmander, Englund, Dahl, & Roos, 2007).

ACL injuries have been recognized as a sports-related injury issue for many years (Mandelbaum et al., 2005; Myklebust et al., 2003; Shultz et al., 2010). It not unusual for athletes to miss one or more seasons of their sport following an ACL tear, which certainly makes it worthwhile to prevent this injury. However, the need for prevention of ACL injuries goes far beyond ability to participate in athletic competitions, as there are a number of other negative consequences associated with ACL injuries.

As might be expected, the financial cost of ACL injuries is detrimental to the injured individual as well as to our society. ACL ruptures usually require surgery and lengthy rehabilitation, and the cost of this for each case of ACL tear has been estimated to be $17,000-25,000 (Hewett, Ford, & Myer, 2006, part 1). The current cost is likely to be even higher, as these figures appear to have been calculated several years ago. Surgeries and rehabilitation for athletic injuries contribute to increased spending on health care. High health care costs are disadvantageous for numerous reasons: they decrease disposable income, make it difficult for employers to offer health care benefits, reduce business profits, contribute to a lower standard of living for senior citizens on fixed incomes, create challenges in acquiring health care for individuals with low incomes or employees who do not have health care coverage from their employer, and consume funds that the government could be using for other purposes (Social Security Advisory Board, 2009). Furthermore, paying the portion of surgery and rehabilitation expenses not covered by health care insurance can be an unexpected financial burden to athletes and their families.

In addition, ACL injuries can have negative impacts on the academic and athletic achievement of student athletes (Freedman, Glasgow, Glasgow, & Bernstein, 1998; Hewett et al., 1999). Promising athletes who rupture an ACL often miss one or more seasons of their sport. Consequently, they can lose skill development in their sport, as well as college scholarships (Hewett et al., 1999). Moreover, time missed from school because of surgery, plus the challenges of undergoing rehab during a school semester can make it difficult for student athletes to keep up with their academic responsibilities (Freedman et al., 1998).

Another harmful consequence of ACL tears is the considerable emotional distress which can occur after the injury. It has been documented that athletes who suffer a sports injury can

experience anger, sadness, frustration, fear, confusion, and depression (Morrey et al., 1999; Leddy, Lambert, & Ogles, 1994). In some cases, sports injuries can result in post-traumatic stress disorder symptoms (Newcomer & Perna, 2003). Injured athletes may also experience reduced self-esteem, loss of athletic identity, and a change in their interactions with teammates and coaches (Leddy et al., 1994; Mankad, Gordon, & Wallman, 2009). In addition, emotional distress due to an injury can reduce adherence to rehabilitation, which may prevent the injured athlete from getting the best physical outcome (Brewer et al., 2000).

Further, the physical limitations experienced after an ACL injury can decrease quality of life for the injured athlete. The recovery and rehabilitation process for ACL injuries is lengthy—often in the range of 6 to 9 months (Atkinson, Laver, & Sharp, 2010; Unwin, 2010). During the first several weeks post-surgery, the individual will have limited used of the repaired knee which can hinder them in their activities of daily living and social life (Mankad et al., 2009). They may be unable to do their normal work, need assistance with transportation and daily activities, and be isolated from friends due to reduced mobility and physical capacity. These issues may add emotional, financial, and relationship stresses to an already challenging situation.

ACL injuries may also negatively impact an individual's future health. ACL ruptures are associated with damage to the menisci, as well as an increased risk of osteoarthritis. (Giugliano & Solomon, 2007; Hewett et al., 2006, part 1; Lohmander et al., 2007; Sadoghi, von Keudell, & Vavken, 2012). Additionally, individuals who sustain an ACL tear may continue to experience deficits in motor control of the affected limb years after surgery (Denti, Randilli, Lo Vetere, Moioli, & Bagnoli, 2000).

Osteoarthritis is a chronic condition that can cause difficulties with working, exercising, and other daily activities. Furthermore, osteoarthritis can contribute to long-term disability

(Lohmander et al., 2007; Hubscher, Zech, Pfeifer, Hansel, Vogt, & Banzer, 2010). Although the reported rate of knee osteoarthritis due to ACL injuries varies, some researchers have evidence to believe that over 50% of individuals who have sustained ACL tears will develop osteoarthritis of the knee (Lohmander et al., 2007). Worse yet, osteoarthritis can occur as soon as 10 years after the injury, and it affects both individuals who receive ACL surgical reconstructions as well as those who receive only non-surgical treatment (Maffulli, Longo, Gougoulias, Loppini, & Denaro, 2010; Lohmander et al., 2007). For example, if a person tears an ACL when they are 18 years old, they could develop osteoarthritis as early as age 28. ACL injuries are thought to be a cause of osteoarthritis of the knee and decreased quality of life for individuals from 30 to 50 years of age (Lohmander et al., 2007).

Who Is at Risk for Sports-Related ACL Injuries

Sports-related ACL injuries are commonly seen in basketball, soccer, volleyball, and team handball (Hutchinson and Ireland, 1995; Heidt, Sweeterman, Carlonas, Traub, & Tekulve, 2000; Hewett et al., 1999; Petersen et al., 2005). These sports can put a high demand on the ACL because they involve frequent cutting, pivoting, and jumping. These team sports have grown in popularity during the last few decades. Furthermore, due to Title IX, more females have been participating in sports. Therefore, more of the population has been exposed to an increased risk of this injury.

Furthermore, female athletes are 4 to 6 times more likely to sustain an ACL injury than males who play the same sports (Hewett et al., 2006; Paterno, Myer, Ford, & Hewett, 2004; Yoo et al., 2010). Various factors contribute to females being more prone to sports-related ACL injuries than males. Among these are differences in strength, anatomy, biomechanics, and hormone profiles (Mandelbaum et al., 2005; Shultz et al., 2010; Shimokochi & Shultz, 2008).

ACL damage can result either from contact between athletes or from the way an athlete lands on the affected limb. Estimates show that 50-80% of ACL injuries are the result of non-contact situations (Myklebust, Maehlum, Holm, & Bahr, 1998; Boden, Dean, Feagin, & Garrett, 2000; Donnelly et al., 2012), such as landing from a jump or coming to an abrupt stop when running. These data suggest that this type of injury might be highly preventable. Because non-contact ACL injuries appear to be preventable, it is prudent to develop and utilize prevention programs to minimize these injuries.

Effectiveness of ACL Injury Prevention Training Programs

Neuromuscular training programs have shown promise for reducing ACL injuries in athletes (Heidt et al., 2000; Hewett et al., 1999; Mandelbaum et al., 2005). Most of these programs include some combination of strength training, balance training, and plyometric training (i.e., exercises such as jumping that cause muscles to quickly stretch and then shorten). Many of them also include focus on movement patterns, especially learning techniques thought to be safer for landing from a jump, accelerating, decelerating, and changing directions quickly (Gilchrist et al., 2008; Heidt et al., 2000; Myklebust et al., 2003). Although it is not yet clear exactly which training components are most protective, it is common to recommend and evaluate neuromuscular programs to reduce the risk of knee injury, and more specifically, ACL injury.

Some of the literature on sports-related ACL tears seems to support the effectiveness of neuromuscular training programs for reducing these injuries (i.e., Caraffa, 1996; Hewett et al., 1999; Mandelbaum et al., 2005; Gilchrist et al., 2008; LaBella et al., 2011). On the contrary, other studies did not support the effectiveness of these programs (i.e., Soderman et al., 2000; Pfeiffer et al., 2006; Petersen et al., 2005; Steffen et al., 2008). Furthermore, Heidt et al., (2000) and Myklebust et al. (2003) found mixed results, showing statistical significance only in a

subgroup of the study participants or a trend toward injury reduction without reaching statistical significance. The studies differed as to the athlete population examined, the components of the programs, the length of the programs, the background and training of the program facilitators, and the results.

Table 1 summarizes 11 studies that evaluated injury prevention neuromuscular training programs. The studies were obtained from a PubMed literature review of peer-reviewed scholarly journals published in English. These particular studies were selected because they investigated ACL injury preventive training programs in team sport athletes. The studies are organized alphabetically in the table.

Table1. Summary of Studies on ACL Injury Prevention Training Programs

Study	Description of Participants	Number of Participants Intv / Ctrl	Study Design	Program Description	ACL Injuries in Intervention Group	ACL Injuries in Control Group	Data Analysis Methods
Caraffa et al. (1996) *	Semi-professional and amateur soccer players (not specified whether male or female)	300 / 300	Non-randomized prospective study	·Pre-season and playing season program: balance and proprioception exercises ·At least 3x per wk for 20 min.	10	70	Chi squared (P < .001)
Gilchrist et al. (2008)	Female college soccer players	583 / 852	Cluster RCT	·At-practice program: stretching, strengthening, agility drills, plyometrics ·3x per wk for 12 wks	2	10	Z-statistic Rate ratios (P < .05)
Heidt et al. (2000)	Female high school soccer players	42 / 258	RCT	·7-week pre-season program: cardiovascular conditioning, plyometrics, strengthening	1	8	Student's t-test (P < .05)
Hewett et al. (1999) *	Female high school soccer, volleyball, and basketball players	366 / 463 females and 434 males	Non-randomized prospective study	·6-week pre-season program: stretching, strengthening, plyometrics; ·3x per wk for 60-90 min.	0	6	Chi squared (P < .05)
LaBella et al. (2011) *	Female high school soccer and basketball players	760 / 798	Cluster RCT	·At-practice warm-up: strengthening, agility, balance, and plyometrics for 20 min. ·Pre-game dynamic warm-up ·Technique instruction	6	2	Chi squared and Fisher exact test Cochran-Armitage test (P< .05)
Mandelbaum et al. (2005) *	Female soccer players (average 14-18 years of age)	*Year 1:* 1041 / 1905 *Year 2:* 844 / 1913	Non-randomized prospective study	·Warm-up program: stretching, strengthening, plyometrics, agility drills for 20 min.	*Year 1:* 2 *Year 2:* 4	*Year 1:* 32 *Year 2:* 35	Relative risk with 95% confidence intervals (P < .05)

Study	Description of Participants	Number of Participants Intv / Ctrl	Study Design	Program Description	ACL Injuries in Intervention Group	ACL Injuries in Control Group	Data Analysis Methods
Myklebust et al. (2003)	Female handball players	*Season 1*: 855 / 942 *Season 2*: 850 / 942	Non-randomized prospective study	Ḗ At-practice program: jumping, running, planting, and balance drills; Ḗ 15 min. 3x per wk for 5-7 wks	*Season 1:* 17 *Season 2:* 14	*Season 1:* 6 *Season 2:* 3	Odds ratio (P < .05)
Petersen et al. (2005)	Female handball players	134 / 142	Non-randomized prospective study	Ḗ At-practice program: balance and jump training for 10 min. Ḗ 3x per wk for 8 weeks in the preseason and then 1x per wk	0	5	Odds ratio with 95% CI
Pfeiffer et al. (2006)	Female high school soccer, basketball, or volleyball players	577 / 862	Non-randomized prospective study	Ḗ At-practice program: plyometrics and agility drills for 20 min.	3	3	Odds ratio (P < .05)
Soderman et al. (2000)	Female soccer players (average 20 years of age)	121 / 100	Cluster RCT	Ḗ Home-based program on balance boards Ḗ 10-15 min. daily for 30 days, and then 3x per week	4	1	Rate ratio with 95% CI (P< .05)
Steffen et al. (2008)	Female soccer players (age 16 or younger)	1100 / 1000	Cluster RCT	Ḗ Warm-up program: stability, balance, and strengthening Ḗ 20 min for 15 consecutive sessions, then 1x per wk	4	5	Z-test with 95% CI Rate ratio (P < .05)

* Indicates that authors found a significant injury reduction effect from intervention

As seen in Table 1, all of the programs studied female athletes except for Caraffa et al., (1996) which did not indicate whether the athletes were male or female. The athletes played soccer, basketball, volleyball, or team handball. Five of the studies were randomized controlled trials and the remaining six were prospective cohort studies. All of the studies used one or more

of the following training methods: Balancing, strengthening, plyometrics, agility drills, and

technique instruction. Four studies showed a significant effect from the training program, six

studies did not have a significant effect, and one study had a significant effect only in the second

part of the season.

Limitations of Existing Studies

All of these studies had some limitations. One flaw in some of the studies was a low

sample size. A sample size that is too small prevents investigators from being able to show

effects that may have existed if more subjects were involved in the study (Statistical Assessment

Service, 2009). In the Heidt et al. (2000), Petersen et al. (2005), and Soderman et al. (2000)

studies there was an issue with having a fewer than ideal number of participants. Heidt et al.,

(2000), whose intervention group contained only 42 participants, stated that significance in the

reduction in ACL injuries may have been established if the intervention group had been larger.

Another common limitation was the inclusion of studies that were not randomized

controlled trials (RCTs). Although all of the studies included control groups, in 6 of 11 studies,

the teams were not randomized. In non-randomized studies, the effects of any confounding

factors are not equalized among the participant groups, and therefore, it may not be possible to

differentiate them from the effects of the intervention. The studies conducted by Hewett et al.

(1999), Mandelbaum et al. (2005), Caraffa et al. (1996), Myklebust et al. (2003), Petersen, et al.

(2005), and Pfeiffer et al. (2006) were not randomized controlled trials. It appears that in some

cases, such as the Pfeiffer et al. study, the investigators would have preferred to randomize the

participants, but were unable for reasons beyond their control, such as many of the coaches and

school administrators not wanting to take part in a randomized study (Pfeiffer et al., 2006). A

possible issue with these non-randomized designs is the possibility of selection bias. In some of

these studies, the teams were not randomly assigned by investigators. Instead, coaches enrolled in the intervention group if they were willing to commit to conducting the intervention training program with their team (Hewett et al., 1999; Mandelbaum et al., 2005; Pfeiffer et al., 2006). Therefore, it is possible that coaches that were more concerned about ACL injuries may have been more likely to participate in the intervention.

Poor compliance was a serious limitation of a few of the studies. Having a substantial number of participants not complete a study is a form of attrition bias. Attrition bias is disadvantageous because it can reduce the generalizability of the study. In addition, participants dropping out of a study leads to incomplete data which can affect the study results (Miller & Hollist, 2007). In the first season of the Myklebust et al. (2003) study, only 26% of teams met the compliance criteria of at least 75% participation in a minimum of 15 sessions during the 5-to-7 week pre-season period. In the second season, even after investigators recruited physical therapists to supervise the training program and record individual athlete compliance, a mere 29% fulfilled the compliance requirements. Furthermore, compliance may have been an issue with the Soderman et al. (2000) study. Participants in the Soderman et al. study performed the balance board training at home. This method relied solely on participant reporting and did not involve any objective confirmation of compliance. Moreover, Petersen et al. (2005) mentioned that some of the coaches were concerned that the injury prevention program might waste valuable practice time. This could indicate that the program may not have been taken seriously or followed carefully by some athletes. Furthermore, two teams in the Petersen et al. intervention group dropped out of the study after only a few weeks.

The Hewett et al. (1999) study had two noteworthy unique limitations. First, the detailed injury data for this study shows that about half of the reported knee injuries were to the medial

collateral ligament (MCL), not the ACL. This can make it more challenging to compare this study's results to results of other studies which only tracked non-contact ACL tears. In addition, Hewett et al. (1999) mentioned that having more volleyball players in the trained group was a limitation of their study. Volleyball players sustain fewer ACL injuries on average than soccer or basketball players (Hutchinson & Ireland, 1995); therefore, it would have been helpful to have nearly equal numbers of athletes from the various sports in the groups.

Furthermore, the studies by Steffen et al., (2008), Soderman et al. (2000), Heidt et al., (2000), and Caraffa et al. (1996) also had a limitation in that they did not differentiate between contact and non-contact ACL tears. This difference makes it difficult to compare these studies' results with studies that only recorded non-contact ACL injuries. This is relevant because non-contact injuries are considered to be preventable, whereas contact injuries may not be.

Existing Programs and Current Needs

Although some of these programs have shown some effectiveness in reducing ACL injuries, more progress is needed in understanding how the programs work, improving the programs, and implementing the programs in the athlete populations that are at high risk (Shultz et al., 2012; Hootman & Albohm, 2012). The overall reduction of sports-related ACL injury is not yet sufficient to provide a substantial improvement in the health of our population and reduction in medical spending (Shultz et al., 2012). Injury epidemiologist Stephen Marshall and colleagues analyzed data on the incidence of cruciate ligament injuries (not only *anterior* cruciate ligament injuries) from 1997-2004, and concluded that in the United States there are 112,500 physician visits for new cruciate ligament injuries each year (Marshall, Padua, & McGrath, 2007). This data indicates that knee ligament injuries and ACL injuries are still a common problem. Although research has suggested that neuromuscular programs have some

benefit for reducing ACL injuries, it appears that the training programs are not being utilized by enough people to have an effect on the overall injury incidence.

Three meta-analyses on ACL injury prevention training programs were found in the literature. These three studies were systematic reviews conducted by different authors and published in different peer-reviewed journals. The Sadoghi et al. meta-analysis (2012) analyzed 8 studies of ACL injury prevention programs, Yoo et al. (2010) analyzed 7 studies, and Hewett et al. (2006) analyzed 6 studies. These three meta-analyses have a number of things in common. All of the authors conducted a thorough computerized search plus a manual search of literature, and developed criteria for the grading the quality of the studies. Likewise, each meta-analysis included only prospective controlled studies on human subjects which contained an intervention for ACL injury prevention. In addition, all of the meta-analysis authors mentioned that heterogeneity of the preventive program components was a hindrance to being able to determine patterns of effectiveness. Finally, the most important similarity of these meta-analyses was that all the authors reached the conclusion that neuromuscular training programs showed some effectiveness in prevention of non-contact ACL injury (Hewett et al., 2006; Yoo et al., 2010; Sadoghi et al., 2012). Table 2 summarizes the three ACL injury prevention program meta-analyses.

Table 2. Summary of Meta-Analyses on ACL Injury Prevention

Study	Number of Studies Included	Inclusion Criteria	Exclusion Criteria	Data Analysis Methods	OR or RR with 95 % CI	Supported Effect of Programs
Hewett et al. (2006)	6	Studied female athletes Studied a neuromuscular training intervention RCTs or prospective cohort studies	Not specified	Odds ratios with 95% confidence intervals	OR (fixed effect): .40 (.26, .61)	Yes
Yoo et al. (2010)	7	Studied female athletes Studied a neuromuscular training intervention RCTs or prospective cohort studies	Not specified	Odds ratios with 95% confidence intervals	OR (fixed effect): .40 (.27, .60) OR (random effect): .49 (.24, 1.02)	Yes
Sadoghi et al. (2012)	8	Prospective controlled studies of human subjects Studied a neuromuscular training intervention	No clinical treatment focus No intervention Animal studies Attrition of > 20%	Risk ratios with 95% confidence intervals	RR (random effect): .38 (.20, .72)	Yes

The three meta-analyses have some differences, as well. An important difference among

the three reviews was that they did not contain all the same studies.   Each of the authors

included these four studies in their reviews: Hewett et al. (1999), Heidt et al. (2000),

Mandelbaum et al. (2005), and Petersen et al. (2005).   None of the meta-analyses included the

Steffen et al. (2008) or the LaBella et al. (2011) studies, which are newer and were not yet

available when the Hewett et al. (2006) and Yoo et al. (2010) studies were published. Table 3

summarizes which studies each meta-analysis included.

Table 3. Differences in Studies Included in 3 Meta-analyses

	Hewett et al. (2006)	Sadoghi et al. (2012)	Yoo et al. (2010)
	Included	Included	Included
Caraffa et al. (1996)		X	
Gilchrist et al. (2008)		X	
Heidt et al. (2000)	X	X	X
Hewett et al. (1999)	X	X	X
LaBella et al. (2011)			
Mandelbaum et al. (2005)	X	X	X
Myklebust et al (2003)	X		X
Petersen et al. (2002)*		X	
Petersen et al. (2005)	X	X	X
Pfeiffer et al. (2006)		X	X
Soderman et al. (2000)	X		X
Steffen et al. (2008)			

*Article published in German language

 In many cases it was not clear why authors excluded certain studies from their meta-analysis. However, Sadoghi et al. did mention that they excluded the Soderman et al. (2000) study due to control group attrition of 22% and intervention group attrition of 49% (Sadoghi et al., 2012). Moreover, it is obvious that the Pfeiffer et al. (2006), Gilchrist et al. (2008), Steffen et al. (2008), and LaBella et al. (2011) studies could not have been included by Hewett et al. (2006), because they were not published when the Hewett review was conducted. For the same reason, the Yoo et al. (2010) meta-analysis also could not include the LaBella et al. (2011) study.

It is noteworthy that the authors of the three existing meta-analyses did not identify barriers to program implementation. Developing awareness of these barriers and overcoming

them is a crucial step in increasing dissemination and implementation of the injury protection programs. Although the training programs do require ongoing improvement and refinement, waiting to utilize the programs until they are comprehensive would not be the best choice. As stated by Hootman and Albohm (2012), thousands of young people may suffer decreased quality of life if the training programs are not made available to the athletes who need them.

Summary

In conclusion, much progress has been made in researching training programs to prevent ACL injuries, but work still remains to be done in understanding why the programs help and in making the programs more available to the athletes that can benefit from them. Previous meta-analyses (Hewett et al., 2006; Yoo et al., 2010; Sadoghi et al., 2012) have indicated that training programs are somewhat effective at preventing ACL injuries; however, the authors did not include in their analyses all the current studies that investigated programs which addressed ACL injury reduction. Furthermore, Hewett et al. (2006) and Yoo et al. (2010) were not explicit about their criteria for exclusion of studies. Therefore, in my proposed study, I intend to consider all of the relevant studies and explain why studies are excluded, as this would provide a more complete and meaningful analysis.

The primary purpose of this proposed study is to determine whether neuromuscular training programs are effective at reducing ACL injuries. This meta-analysis will consider two newer studies and the studies excluded from some of the previous meta-analyses. A secondary purpose of this proposed study is to identify and describe some common barriers to implementation for these training programs. Due to the fact that ACL tears are serious injuries which can have long-term adverse effects, there is a need to better understand both the effectiveness of preventive programs and the obstacles that are hindering the widespread use of

the programs. Therefore, this investigation will address the following research questions: 1) Are neuromuscular training programs effective at reducing ACL injuries, and 2) What are the barriers to implementation of these training programs.

Chapter 3: Methods

Search Strategy

      After communicating with the UMCIRB, we were notified that an IRB submission was not required for this study (see appendix B). A systematic review of literature was conducted on anterior cruciate ligament injury prevention programs by searching Medline and the Cochrane Library. The keywords õanterior cruciate ligament,ö õinjury,ö and õpreventionö were used to conduct the search. In addition, since a number of meta-analyses and systematic reviews are available on this topic, those articles were retrieved from the primary search and checked to ensure that relevant studies were not being overlooked from our search. A secondary search in the reference lists of articles to be included was conducted to identify other relevant articles which were not located by the online database search. A summary of the search process follows in Figure 1.
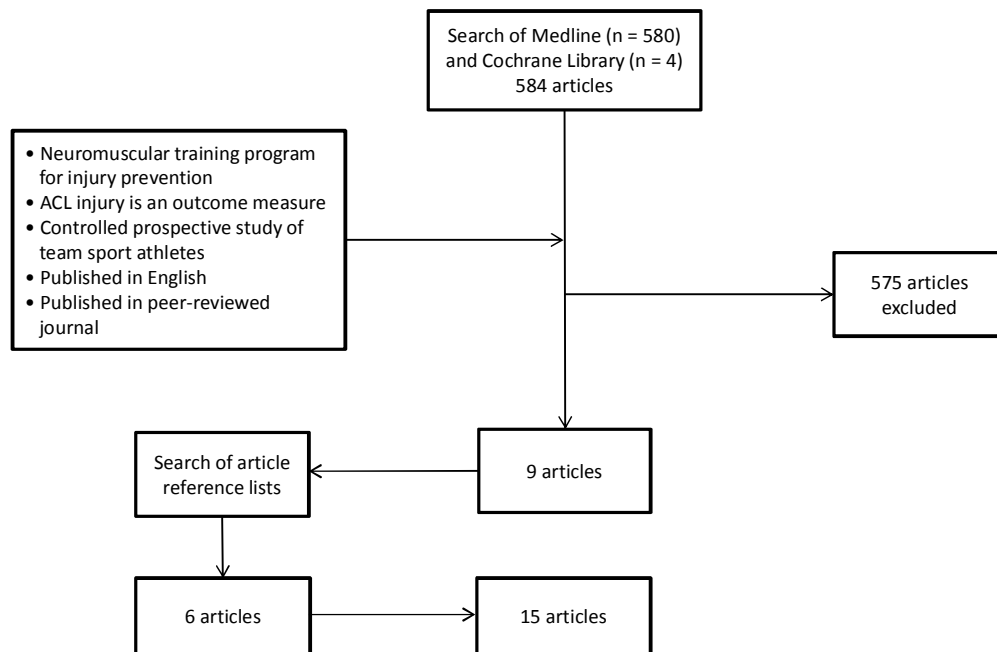
Figure 1. Flowchart of literature search

Criteria for Inclusion

We included only prospective, controlled studies of team sport athletes which evaluated a neuromuscular training program for injury prevention and reported ACL injury as an outcome measure. Further, we required that studies be published in English in a peer-reviewed journal. Both randomized controlled trials and non-randomized prospective cohort studies were included in the primary meta-analysis.

Criteria for Exclusion

We excluded from the primary meta-analysis studies which did not differentiate between contact and non-contact ACL injuries. These studies were excluded because rates of effectiveness for neuromuscular training programs are likely to be different for the two

mechanisms of injury. However, these studies will be included in a sensitivity analysis to test the robustness of the primary meta-analysis. In addition, we excluded studies that investigated ACL injuries in individual sport athletes. These studies were excluded because intervention programs for individual sport athletes, such as skiing, are likely to be different than those for team sport athletes.

Evaluation of Included Studies

The included studies were evaluated for quality by two evaluators, working independently. When there was a discrepancy between evaluators' results, the items were discussed and consensus reached. First, the Levels of Evidence table (Oxford Centre for Evidence Based Medicine, 2009) was used to assess the level of research design for each study. Second, the methodological quality of each study was assessed with the PEDro scale (Centre of Evidence-Based Physiotherapy, 2012) (Maher et al., 2003).

The Levels of Evidence Table from the Centre for Evidence Based Medicine at Oxford University is an evidence-ranking heuristic. It was designed to help clinicians, researchers, and patients in decision making about treatment options by providing a system for evaluating the evidence provided by research. The table is comprised of 5 numeric levels, some of which have alphabetic sub-levels. Level 1a (a systematic review of RCTs with homogeneity) is the highest level of evidence and level 5 (expert opinion) is the lowest. Treatment options can be given grades (A through D) based on the quality of the research studies that support their results (Oxford Centre for Evidence Based Medicine, 2009).

The PEDro scale, developed and managed by the Centre of Evidence-Based Physiotherapy, is a list of 11 criteria for evaluating the methodological quality of research studies. Item 1 assesses external validity, items 2-9 assess internal validity, and items 10 and 11

assess statistical quality (see Table 5 legend for a list of the criteria). Except for the first item, one point is tallied for each yes answer, and the total score provides an estimate of the quality of a study (Centre of Evidence-Based Physiotherapy, 2012; Maher et al., 2003).

Meta-analysis

We used a risk ratio to measure effect size. Risk ratios were calculated by dividing the experimental group event rate (i.e., ACL injury) by the control group event rate. We chose the risk ratio instead of the odds ratio because for a study on injury prevention, evaluating a reduction in the risk of an event would be easier to understand and interpret. Specifically, a risk ratio indicates what percentage of the total number of participants was injured. We evaluated the heterogeneity of the studies using the Cochran Q statistic and the I^2 test. The Q-statistic was used to evaluate whether the magnitude of heterogeneity was significant, but this test has been shown to have low statistical power if there are few studies in a meta-analysis (Deeks et al., 2008). Therefore, the I^2 was used to estimate the magnitude of heterogeneity with 0-40% (õmay not be importantö), 30-60% (moderate heterogeneity), 50-90% (õmay represent substantial heterogeneityö), and 75-100% (considerable heterogeneity), (Deeks et al., 2008). We conducted a meta-analysis of pooled intervention effects using the Mantel-Haenszel method for fixed effects results. When significant heterogeneity was detected through the Q-statistic, the DerSimonian and Laird random-effects method was used. Furthermore, two sensitivity analyses were performed to test the robustness of the results with the specified inclusion criteria: 1) all ACL injuries (instead of only non-contact injuries), and 2) only randomized trials (instead of both randomized and non-randomized studies). Statistical analyses were conducted using a custom spreadsheet program within Microsoft Excel 2010.

Barriers to Implementation

Despite the fact that research indicates that neuromuscular training programs are somewhat effective in reducing ACL injuries (Hewett, 1999; Mandelbaum, 2005; Gilchrist, 2008; LaBella, 2011), the overall incidence of ACL injury are still fairly high (Marshall, 2007). Therefore, we conducted a qualitative examination of some of the barriers to implementation of ACL injury prevention programs and we identified five common barriers to implementation by analyzing the articles in our study. We utilized the Socio-Ecological Model to identify and organize some ideas for addressing the identified barriers to implementation.

Chapter 4: Results

Characteristics of Reviewed Studies

Table 4 summarizes the characteristics of the 15 included studies. The athletes who participated in the studies played soccer, basketball, volleyball, team handball, or floorball (a type of floor hockey). All of the programs studied female athletes, except for Caraffa et al., (1996) which did not indicate whether the athletes were male or female. All of the studies used one or more of the following training methods: Balancing, strengthening, plyometrics, agility drills, and technique instruction.

Eight of the studies were randomized controlled trials and seven were prospective cohort studies. Eight studies supported a significant effect from the training program (Caraffa et al., 1996; Hewett et al., 1999; Kiani et al., 2010; LaBella et al., 2011; Mandelbaum et al., 2005; Olsen et al., 2005; Pasanen et al., 2008; Walden et al., 2012), six studies did not show a significant effect (Heidt et al., 2000; Myklebust at al., 2003; Petersen et al., 2005; Pfeiffer et al., 2006; Soderman et al., 2000; and Steffen et al., 2008), and one study had a significant effect only in the second part of the season (Gilchrist et al., 2008).

Table 4. Injury Prevention Neuromuscular Training Programs Analyzed in Present Study

Study	Description of Participants	Number of Participants Intv / Ctrl	Study Design	Program Description	ACL Injuries in Intervention Group	ACL Injuries in Control Group
Caraffa et al. (1996)	Semi-professional and amateur soccer players (not specified whether male or female)	300 / 300	Non-randomized cohort study	ƒPre-season and playing season program: balance and proprioception exercises ƒAt least 3x per wk for 20 min.	10	70
Gilchrist et al. (2008)	Female college soccer players	583 / 852	Cluster RCT	ƒAt-practice program: stretching, strengthening, agility, plyometrics ƒ3x per wk for 12 wks	2	10

Study	Description of Participants	Number of Participants Intv / Ctrl	Study Design	Program Description	ACL Injuries in Intervention Group	ACL Injuries in Control Group
Heidt et al. (2000)	Female high school soccer players	42 / 258	RCT	• 7-week pre-season program: cardiovascular conditioning, plyometrics, strengthening	1	8
Hewett et al. (1999)	Female high school soccer, volleyball, and basketball players	366 / 463 females and 434 males	Non-randomized cohort study	• 6-week pre-season program: stretching, strengthening, plyometrics; • 3x per wk for 60-90 min.	0	6
Kiani et al. (2010)	Female soccer players (age 13-19)	777 / 729	Non-randomized cohort study	• Preseason and playing season program: muscle activation strengthening, core stability, balance • 1 or 2x per wk for 20-25 min.	0	5
LaBella et al. (2011)	Female high school soccer and basketball players	760 / 798	Cluster RCT	• At-practice warm-up: strengthening, agility, balance, and plyometrics for 20 min. • Pre-game dynamic warm-up • Technique instruction	6	2
Mandelbaum et al. (2005)	Female soccer players (average 14-18 years of age)	*Year 1:* 1041 / 1905 *Year 2:* 844 / 1913	Non-randomized cohort study	• Warm-up program: stretching, strengthening, plyometrics, agility drills for 20 min.	*Year 1:* 2 *Year 2:* 4	*Year 1:* 32 *Year 2:* 35
Myklebust et al. (2003)	Female handball players	*Season 1:* 855 / 942 *Season 2:* 850 / 942	Non-randomized cohort study	• At-practice program: jumping, running, planting, and balance drills; • 15 min. 3x per wk for 5-7 wks	*Season 1:* 17 *Season 2:* 14	*Season 1:* 6 *Season 2:* 3
Olsen et al. (2005)	Male and female hand ball players (age 15-17)	958 / 879	Cluster RCT	• Warm-up program: Running, strengthening, balance, technique • 15-20 min. for 15 practices; then 1x per wk	3	10
Pasanen et al. (2008)	Female floorball players	256 / 201	Cluster RCT	• At-practice program: running, balance, plyometrics, strengthening • 20-30 min. 1-3x per wk	4	6

Study	Description of Participants	Number of Participants Intv / Ctrl	Study Design	Program Description	ACL Injuries in Intervention Group	ACL Injuries in Control Group
Petersen et al. (2005)	Female handball players	134 / 142	Non-randomized cohort study	• At-practice program: balance and jump training for 10 min. • 3x per wk for 8 weeks in the preseason and then 1x per wk	0	5
Pfeiffer et al. (2006)	Female high school soccer, basketball, or volleyball players	577 / 862	Non-randomized cohort study	• At-practice program: plyometrics and agility drills for 20 min.	3	3
Soderman et al. (2000)	Female soccer players (average 20 years of age)	121 / 100	Cluster RCT	• Home-based program on balance boards • 10-15 min. daily for 30 days, and then 3x per week	4	1
Steffen et al. (2008)	Female soccer players (age 16 or younger)	1100 / 1000	Cluster RCT	• Warm-up program: stability, balance, and strengthening • 20 min for 15 consecutive sessions, then 1x per wk	4	5
Walden et al. (2012)	Female soccer players (age 12-17)	2479 / 2085	Cluster RCT	• Warm-up program: knee control, core stability, jumping technique • 15 min. 2x per wk	7	14

Design Quality and Evidence of Reviewed Studies

Table 5 shows CEBM levels of evidence and PEDro scores for the 15 studies. Seven studies were rated as evidence level 1b and eight studies were rated as evidence level 2b. The average PEDro score for the studies was 4.67 with a high score of 8 and a low score of 2. Consensus was reached between evaluators on all levels of evidence and PEDro scores.

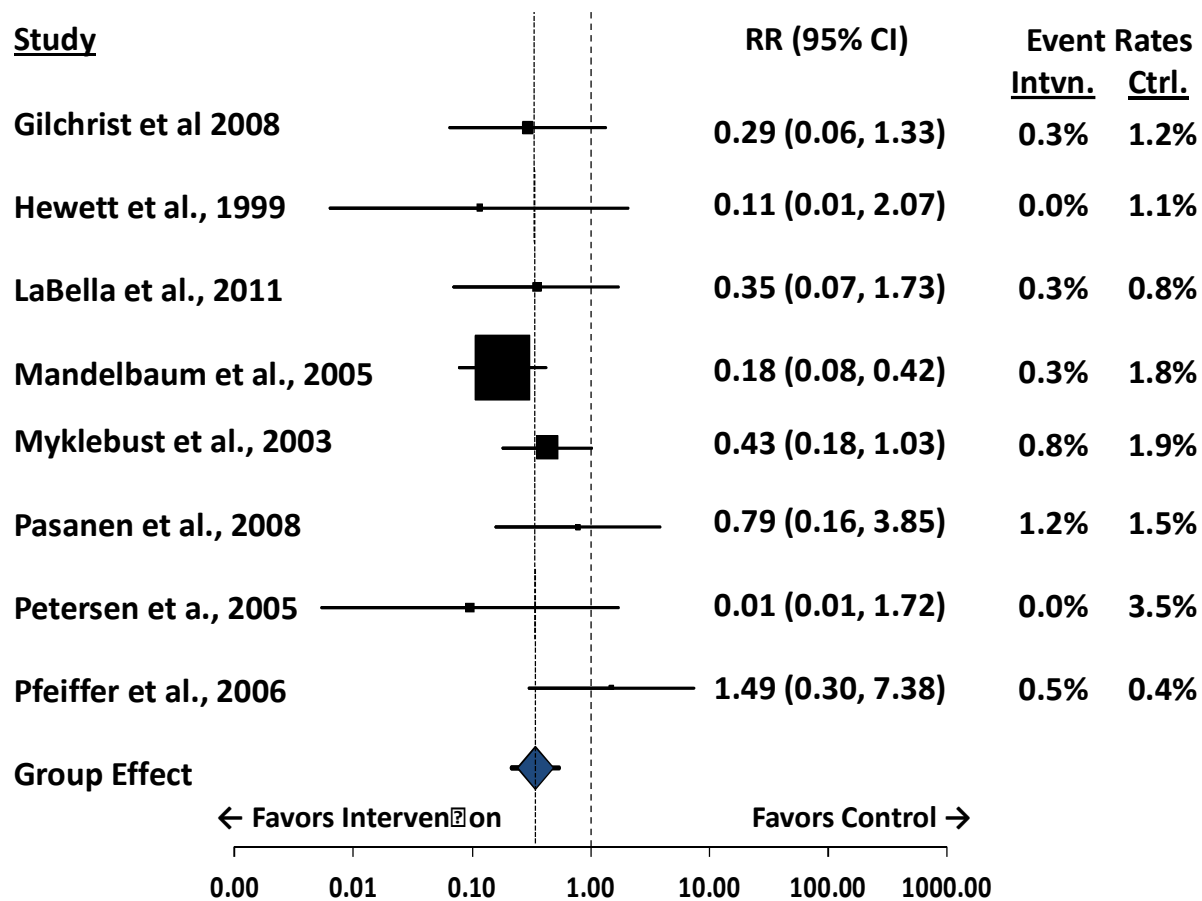**Table 5. Ratings of Study Design and Methodological Quality**

Study / Date	CEBM level of evidence	PEDro score	1	2	3	4	5	6	7	8	9	10	11
Caraffa et al., 1996	2b	2	_			Y						Y	
Gilchrist et al., 2008	1b	4	_	Y		Y						Y	Y
Heidt et al., 2000	1b	4	_	Y					Y	Y		Y	
Hewett et al., 1999	2b	3	_							Y	Y	Y	
Kiani et al., 2010	2b	4	_			Y			Y			Y	Y
LaBella et al., 2011	1b	6	_	Y		Y				Y	Y	Y	Y
Mandelbaum et al., 2005	2b	3	_							Y		Y	Y
Myklebust et al., 2003	2b	4	_							Y	Y	Y	Y
Olsen et al., 2005	1b	7	_	Y		Y			Y	Y	Y	Y	Y
Pasanen et al., 2008	1b	8	_	Y	Y	Y			Y	Y	Y	Y	Y
Petersen et al., 2005	2b	2	_									Y	Y
Pfeiffer et al., 2006	2b	2	_									Y	Y
Soderman et al., 2000	2b	4	_	Y		Y						Y	Y
Steffen et al., 2008	1b	7	_	Y	Y				Y	Y	Y	Y	Y
Walden et al., 2012	1b	7	_	Y	Y	Y			Y		Y	Y	Y

Y indicates criterion was met; 1 = eligibility criteria specified; 2 = random allocation of participants; 3 = allocation concealed; 4 = groups similar at baseline; 5 = blinding of subjects; 6 = blinding of intervention providers; 7 = blinding of outcome assessors; 8 = key outcomes from > 85% of participants; 9 = intention to treat protocol used; 10 = between groups comparison; 11 = point measures and measures of variability provided

Data Synthesis

Primary meta-analysis. The results of the primary meta-analysis are shown in Figure 2. This meta-analysis evaluated the group effects of the studies reporting non-contact injuries separately from contact injuries. In this analysis, we found a pooled risk ratio of 0.30 with 95% confidence intervals of 0.19 to 0.47 ($p = < .001$). No significant heterogeneity was found ($Q = 8.46$, $I^2 = 0.17$), so a fixed effect model was used. Mandelbaum et al. (2005) accounted for the highest weighting in this analysis, whereas Pfeiffer et al. (2006) was weighted the lowest.

Study		RR (95% CI)	Event Rates	
			Intvn.	Ctrl.
Gilchrist et al 2008		0.29 (0.06, 1.33)	0.3%	1.2%
Hewett et al., 1999		0.11 (0.01, 2.07)	0.0%	1.1%
LaBella et al., 2011		0.35 (0.07, 1.73)	0.3%	0.8%
Mandelbaum et al., 2005		0.18 (0.08, 0.42)	0.3%	1.8%
Myklebust et al., 2003		0.43 (0.18, 1.03)	0.8%	1.9%
Pasanen et al., 2008		0.79 (0.16, 3.85)	1.2%	1.5%
Petersen et a., 2005		0.01 (0.01, 1.72)	0.0%	3.5%
Pfeiffer et al., 2006		1.49 (0.30, 7.38)	0.5%	0.4%
Group Effect				

← Favors Interven on   Favors Control →

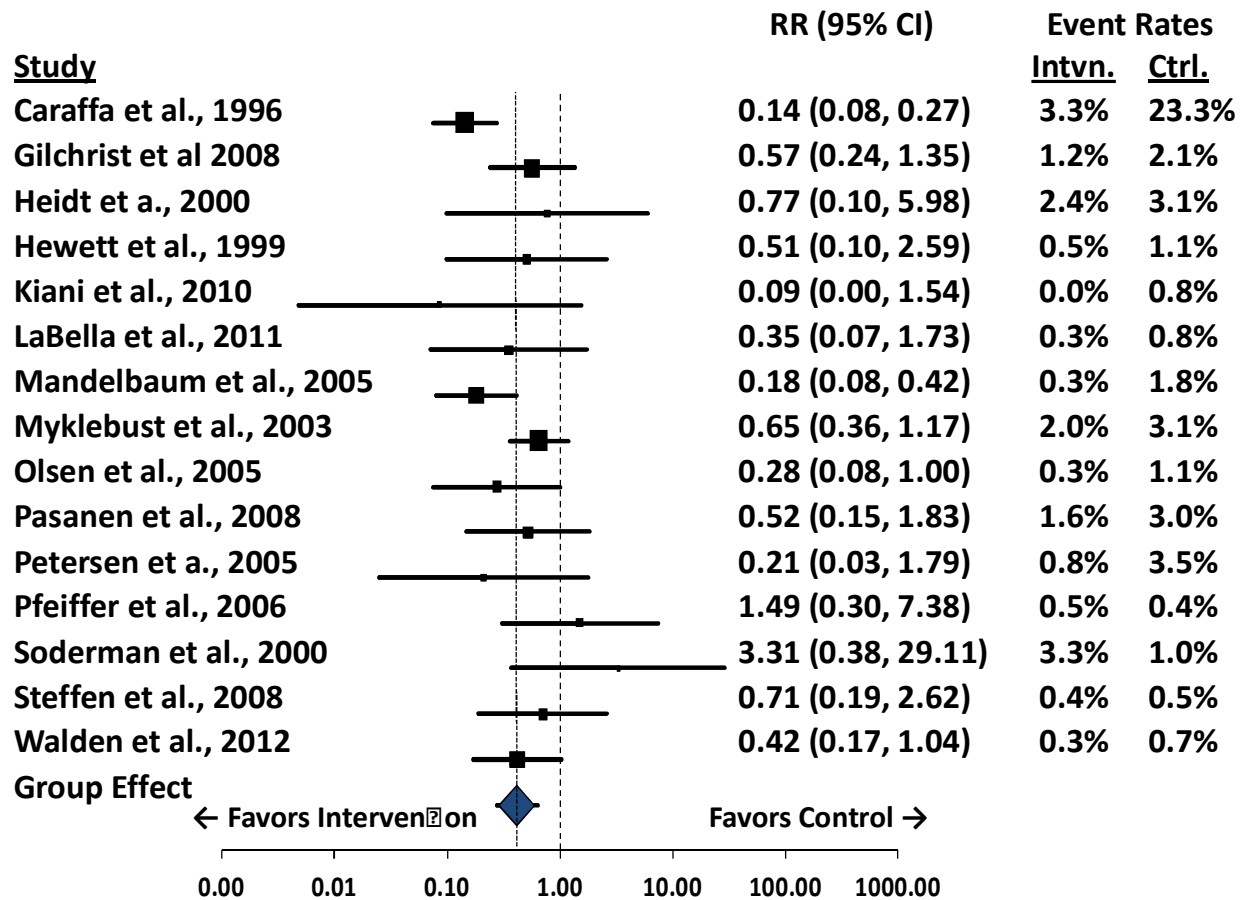0.00   0.01   0.10   1.00   10.00   100.00   1000.00

Figure 2. Effect of ACL injury prevention programs on non-contact ACL injury
Legend: Only noncontact ACL injuries reported were included in analysis; Fixed effects model used; Group effect: Z = 5.26; P = <0.001; Heterogeneity: Q = 8.46, df = 7, P= 0.29, I^2 = .17; Intvn = intervention group; Ctrl = control group; Event rates calculated as the percentage of noncontact

ACL injuries in the group (rounded to nearest tenth of percent). X-axis plotted on logarithmic scale. Value at 0.00 is 0.001 rounded to 2 decimal places. 1.0 (thick dotted line) = intervention and control groups have equal risk of sustaining any ACL injury. Thin dotted line = group effect: relative risk = 0.30 (0.19, 0.47).


Sensitivity analyses. The results of the first sensitivity analysis are presented in Figure

3. This meta-analysis included all 15 studies, incorporating both contact and noncontact ACL

injuries, and produced an overall risk ratio of 0.41 with 95% confidence intervals of 0.27 to 0.63.

The preventive effect of the training programs was significant ($p = < 0.001$). Significant

between-study heterogeneity was found ($Q = 25.28$, $I^2 = .46$, $^2 = .27$); therefore, a random

effects model was used.

Study		RR (95% CI)	Event Rates Intvn.	Ctrl.
Caraffa et al., 1996		0.14 (0.08, 0.27)	3.3%	23.3%
Gilchrist et al 2008		0.57 (0.24, 1.35)	1.2%	2.1%
Heidt et a., 2000		0.77 (0.10, 5.98)	2.4%	3.1%
Hewett et al., 1999		0.51 (0.10, 2.59)	0.5%	1.1%
Kiani et al., 2010		0.09 (0.00, 1.54)	0.0%	0.8%
LaBella et al., 2011		0.35 (0.07, 1.73)	0.3%	0.8%
Mandelbaum et al., 2005		0.18 (0.08, 0.42)	0.3%	1.8%
Myklebust et al., 2003		0.65 (0.36, 1.17)	2.0%	3.1%
Olsen et al., 2005		0.28 (0.08, 1.00)	0.3%	1.1%
Pasanen et al., 2008		0.52 (0.15, 1.83)	1.6%	3.0%
Petersen et a., 2005		0.21 (0.03, 1.79)	0.8%	3.5%
Pfeiffer et al., 2006		1.49 (0.30, 7.38)	0.5%	0.4%
Soderman et al., 2000		3.31 (0.38, 29.11)	3.3%	1.0%
Steffen et al., 2008		0.71 (0.19, 2.62)	0.4%	0.5%
Walden et al., 2012		0.42 (0.17, 1.04)	0.3%	0.7%
Group Effect				

← Favors Interven on   ◆   Favors Control →

0.00   0.01   0.10   1.00   10.00   100.00   1000.00

Figure 3. Effect of ACL injury prevention programs – all reviewed studies
Legend: All studies reporting any ACL injury included in analysis; random effects model used; Group effect: Z = 4.13; P = <0.001; Heterogeneity: Q = 25.82, df = 14, P = .03, I^2 = .46; τ^2 = .27; Intvn = Intervention group; Ctrl = control group; Event rates calculated as the percentage of ACL injuries in the group (rounded to nearest tenth of percent). X-axis plotted on logarithmic scale. Value at 0.00 is 0.001 rounded to 2 decimal places. 1.0 (thick dotted line) = intervention and control groups have equal risk of sustaining any ACL injury. Thin dotted line: relative risk for group effect = 0.41 (0.27, 0.63).

The results of the second sensitivity analysis are shown in Figure 4. This meta-analysis evaluated the pooled effects of only the randomized controlled trials. We found a risk ratio of 0.52 with 95% confidence intervals of 0.34 to 0.80. The preventive effect of the training programs was significant ($p = < 0.01$). No significant between-study heterogeneity was found ($Q = 4.55$, $I^2 = 0.00$), so a fixed effect model was used.
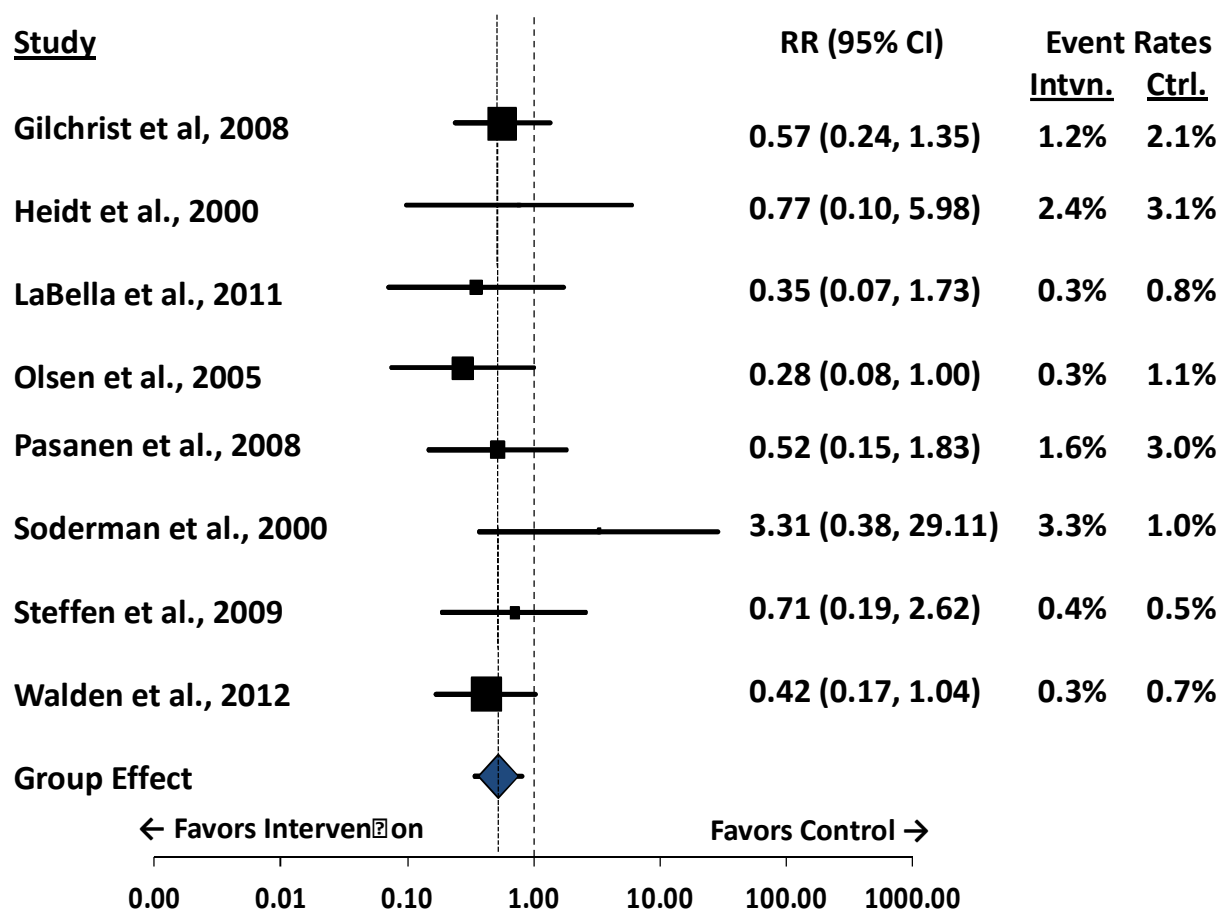
Figure 4. Effect of ACL injury prevention programs on ACL injury – RCTs
Legend: All ACL injuries reported from randomized controlled trials were included in analysis;
Fixed effects model used; Group effect: Z = 2.98; P = <0.01; Heterogeneity: Q = 4.55, df =7, P =
0.71, I^2 = 0.00; Intvn = Intervention group; Ctrl = control group; Event rates calculated as the
percentage of ACL injuries in the group (rounded to nearest tenth of percent). X-axis plotted on
logarithmic scale. Value at 0.00 is 0.001 rounded to 2 decimal places. 1.0 (thick dotted line) =
intervention and control groups have equal risk of sustaining any ACL injury. Thin dotted line =
group effect: relative risk = 0.52 (0.34, 0.80).

    Data summary. In summary, as compared to not having a specific injury prevention

program, use of neuromuscular training programs significantly reduced non-contact ACL

injuries with a relative risk of 0.30 (95% CI: 0.19, 0.47). This overall effect corresponded to a

70% reduction in relative risk in the intervention groups as compared to the control groups. Both

of the sensitivity analyses confirmed that the overall interpretation of ACL injuries being

effective for reducing ACL injuries was not dependent on our inclusion criteria. When including all ACL injuries (sensitivity analysis 1), the relative risk was 0.41 (95% CI: 0.27, 0.63), which corresponds to a 59% relative risk reduction. However, this analysis also resulted in significant heterogeneity, suggesting that there are various intervention effects across the included studies. The assessment of ACL injury prevention programs using only randomized controlled trials (sensitivity analysis 2) resulted in a significant effect with a relative risk of 0.52 (95% CI: 0.34, 0.80). This sensitivity analysis corresponded to a 48% reduction in relative risk compared to the control groups. While all three meta-analyses produced similar results in the overall interpretationô neuromuscular training programs are effective in reducing ACL injuries, the most conservative relative risk (0.52) was found in our meta-analysis of only the randomized controlled trials (sensitivity analysis 2).

Barriers to Implementation

To date, very little research has been conducted on barriers to implementing ACL injury prevention programs, and some researchers have been urging that more attention be paid to identifying and overcoming these kinds of barriers (Shultz et al., 2012; Hootman et al., 2012). By qualitatively examining the articles used in our meta-analysis, it is possible to identify some of these potential barriers. Identifying and addressing program barriers may be beneficial for improving program effectiveness, advancing program development, and increasing use of the programs. We found the following five barriers mentioned throughout our reviewed literature: Motivation, time requirements, skill requirements for program facilitators, cost, and compliance.

Motivation. Low motivation to participate can be a substantial barrier to implementation for ACL injury prevention programs. Low motivation from athletes and/or coaches can result from lack of confidence about the programsøeffectiveness. Kiani et al. (2010) found that some

coaches declined to participate because they were skeptical about the effectiveness of the program. Furthermore, low motivation can arise from boredom with the exercises or exercises that are not challenging enough. For example, Steffen et al., (2008) stated that having their intervention group athletes perform the same 10 exercises in every practice session without varying the exercises or increasing the intensity may have contributed to a decrease in motivation among the athletes and coaches. The authors reported that their preventive program was utilized at 60% of all training sessions in the first half of the season and 44% in the second half of the season. In addition, resistance to change may be a cause of low motivation to participate in injury prevention training programs. Pfeiffer et al. (2006) noted that many coaches were not willing to change their practice protocols.

Time requirements. Since sports training time is limited and there are various components of training that coaches need to cover with their athletes, the time required to conduct an injury prevention program may be a barrier to regular use of preventive programs. This appears to have been an issue for Steffen et al. (2008) who conducted their study with teams which practiced once or twice a week and had competitions on weekdays. The authors felt that this kind of schedule made it difficult to consistently include preventive training. Furthermore, Petersen et al. (2005) stated that some coaches in their study were concerned that the preventive exercises would take up valuable training time. Among the 15 studies we considered, the time spent on the neuromuscular training program ranged from 10 minutes to 90 minutes per session.

Skill requirements for program facilitators. It is logical to expect that exercises must be performed with correct technique to reap the intended benefits of the exercises, and that not doing this can be a potential barrier to program effectiveness. Several authors emphasized the importance of technique, reporting that their intervention group participants were taught proper

technique for the preventive exercises or encouraged to pay attention to performing the exercises with good form (i.e., Myklebust et al., 2003; Olsen et al., 2005; Steffen et al., 2008; Hewett, et al., 1999; Pasanen et al., 2010; Walden et al., 2012). In addition, the preparation and physical fitness of the program facilitator may have an impact on the quality of program implementation. LaBella et al. (2011) observed that certain coaches in their study included fewer of the program exercises. They suggested that these coaches who were overweight or older may have omitted exercises they could not demonstrate.

A similar matter that deserves attention is whether it is best for coaches or health professionals (e.g., certified athletic trainers, physical therapists) to lead the training program. Many of the studies we examined had coaches leading the training programs (i.e., Walden et al. 2012; LaBella et al., 2011; Steffen et al., 2008; Kiani et al., 2008; Mandelbaum et al., 2005; Olsen et al., 2005), whereas some had physical therapists or certified athletic trainers (Gilchrist et al., 2008; Myklebust et al., 2003), and a few had coaches and physical therapists or athletic trainers (Pasanen et al., 2008; Petersen et al., 2005; Hewett et al., 1999). There are advantages to coach-led programs, such as athletes knowing and respecting their coach (which may increase the likelihood of putting forth good effort in training) and cost-savings to the school or club due to not needing to hire a health professional to oversee the training. Similarly, there are advantages to health professional-led programs, such as the knowledge and skill to ensure that the program is conducted properly and busy coaches being relieved from the responsibility of injury prevention training. Nevertheless, it is essential that whoever facilitates an injury prevention program be knowledgeable about proper exercise technique, be able to give clear instructions, and be willing to carefully monitor athletes to ensure they are doing the exercises correctly.

Compliance. Poor compliance with an injury prevention training program can also present a barrier to obtaining satisfactory results from the program. Steffen et al. (2008) attributed the lack of effect in their injury prevention program to insufficient compliance. In their study, the training program was used by intervention group teams in 52% of the practice sessions. Furthermore, Myklebust et al. (2003) had only a 29% compliance rate in their study. They found this surprising because of the media attention given to the problem of ACL injuries and because they had physical therapists monitor their intervention teams to improve compliance. Both of these studies failed to demonstrate a significant effect from their intervention training programs.

Sugimoto et al. (2012) conducted a small meta-analysis on compliance with neuromuscular training programs using the previously-mentioned ACL injury prevention studies by Hewett et al. (1999), Soderman et al. (2000), Heidt et al. (2000), Myklebust et al. (2003), Steffen et al. (2008), and Kiani et al. (2010). Sugimoto et al. (2012) found that lower compliance was associated with higher rates of ACL injury among participants in injury prevention training program studies. This study further supports the premise that adequate compliance is an integral part of an effective ACL injury prevention program. It is also possible that low motivation, unacceptable program time requirements, or inadequate skilled program facilitators can have a negative impact on compliance.

Cost. The cost of ACL injury prevention training programs is another potential barrier to implementation that should be considered. In their meta-analysis of ACL injury prevention programs, Hewett et al. (2006, part 2) estimated that program costs range from $10 for a video to $375 per athlete for a commercial trainer-led program. Likewise, LaBella et al. (2011) reported that the cost of training the coaches for their study was $80 per coach. With tighter budgets for

schools and community programs in recent years, the cost of equipment, facilitator training, and assistance by health professionals for preventive programs may present a barrier to some teams. However, it should be noted that these many of the costs would cover an entire team (or more than one team), so the programs may still offer an excellent cost-to-benefit ratio. Although we did not conduct a formal cost-benefit analysis, given that rehabilitation of a single ACL injury is estimated to cost $17,000-$25,000 (Hewett et al., 2006, part 1), it seems that the costs for prevention would be less than the costs for post-injury management. This area warrants further research.

Chapter 5: Discussion

Comparison to Other Meta-Analyses

Table 6. Comparison with Summary Statistics from Other Meta-analyses

Study	Median Control Risk	Relative Risk *			Numbers Needed to Benefit **		
		Mean	Lower	Upper	Mean	Lower	Upper
Hewett et al. (2006)	0.0242	0.41	0.26	0.62	70	56	108
Yoo et al. (2010)	0.0221	0.41	0.27	0.61	76	62	115
Sadoghi et al. (2012)	0.0261	0.38	0.20	0.72	62	48	137
Current study ó non-contact ACL injuries	0.0133	0.30	0.19	0.47	107	93	141
Current study ó All ACL injuries	0.0114	0.41	0.27	0.63	149	120	236
Current studyó RCTs	0.0107	0.52	0.34	0.80	196	142	471

*Risk ratios converted from reported odds ratios using each studyø median control risk
**Numbers needed to benefit calculated assuming the median control risk from each study

Our meta-analyses support our hypothesis that neuromuscular training programs are effective for reducing ACL injuries in team sport athletes. Our primary meta-analysis indicated that the risk of non-contact ACL injuries was reduced in the intervention groups by 70% (95% CI: 53-81%) in comparison to the control groups. Likewise, both of our sensitivity analyses indicated that the training programs were effective. The most conservative results were found in the analysis of only randomized controlled trials, which corresponded to a reduction in relative risk of 48% (95% CI: 20-66%). As we will discuss next, the risk ratios reported in this meta-analysis (i.e., primary meta-analysis: 0.30 [0.19, 0.47], all studies sensitivity analysis: 0.41 [0.27, 0.63], only RCTs sensitivity analysis: 0.52 [0.34 to 0.80]) are consistent with findings of

previous meta-analyses (i.e., Hewett et al., 2006, Yoo et al., 2010; Sadoghi et al., 2012) when considering the 95% confidence intervals (see Table 6).

In their meta-analysis, Hewett et al. (2006) reported an odds ratio of 0.40 (95% CI 0.26, 0.61). When converted to a risk ratio (with assumed median control group risk of 2.42%) this would be equivalent to 0.41(95% CI 0.26, 0.62). In their meta-analysis, Yoo et al. (2010) reported an odds ratio of 0.40 (95% CI 0.27, 0.60), which corresponds to a risk ratio of 0.41 (95% CI 0.27, 0.61) when using a median control group risk of 2.21%. In their meta-analysis, Sadoghi et al. (2012) found a risk ratio of 0.38 (95% CI 0.20, 0.72). In sum, the findings of these meta-analyses appear consistent with our findings despite differences in the designs of the studies analyzed as well as in the inclusion and exclusion criteria of the meta-analyses. However, because criteria for study inclusion was varied and the presence of significant heterogeneity was not uniform across studies, the magnitude of the õactualö treatment effect is not able to be pinpointed to a specific number, as our risk ratio summary statistics range from 30-52%.

Recommendations to Improve Program Implementation

Addressing barriers with the socio-ecological model. Since there are a variety of factors that can contribute to sub-optimal implementation and success of ACL injury prevention programs, the broad perspective of the Socio-Ecological Model (SEM) may be beneficial for understanding and organizing possible solutions. The SEM is a framework that explains behavior as being influenced by five factors which are represented by concentric bands (Figure 5). The innermost section is the individual or intrapersonal level, which is surrounded by interpersonal, organizational, community, and public policy factors (Richard et al., 1996; McLeroy et al., 1988). The SEM is commonly used for developing health promotion

interventions because it goes beyond just individual influences on behavior and considers an assortment of environmental factors that can also affect behavior. The Centers for Disease Control and Prevention developed its colorectal cancer control program on the SEM (CDC, 2013). Similarly, other health promotion studies have utilized the SEM to analyze contributing factors and develop interventions for an obesity prevention program (Pratt et al., 2007), to increase fruit and vegetable intake (Robinson, 2008), and to analyze enablers and inhibiters to physical activity (Siddiqi et al., 2011).
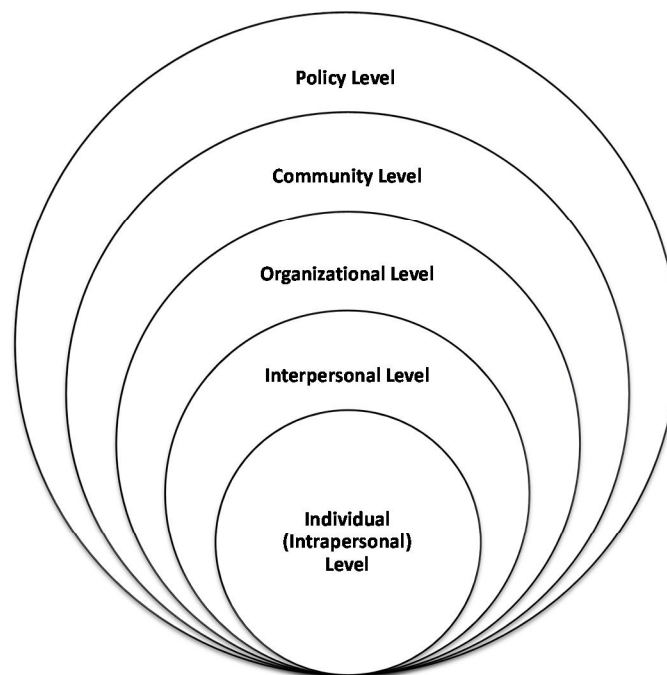
Figure 5. Representation of socio-ecological model

Individual level. When applying the SEM to ACL injury prevention, the individual level represents the athletes. One method that could improve implementation on the individual level is awareness and education. This could address the motivation and compliance barriers.

Myklebust et al. (2003) suggested that better communication may be needed so that athletes will understand that knee function may not return to normal after an ACL injury. Education and building of awareness should go beyond a lecture on ACL injuries. Ideas for effective education about ACL injuries could include opportunities for athletes to interact with each other around the topic (e.g., group projects or discussions), the use of a realistic anatomical model of the knee, and a post-instructional assessment.

A second strategy focused on the individual athlete would be to increase motivation to participate in the program by broadening the scope of the injury prevention program. Including sport-specific performance improvement components in the injury prevention program would provide athletes the added benefit of enhancing their sport-specific skills. Petersen et al. (2005) noted that many coaches in their study wanted injury prevention exercises combined with handball-specific exercises. Adding sport-specific elements to the preventive training might facilitate making the program more interesting and could also improve program compliance.

Interpersonal level. The interpersonal level would focus on coaches, parents, and teammates. As with the individual level, awareness and education about ACL injuries is a strategy to improve adoption of training programs among coaches. This could include clearly communicating to coaches and parents that ACL injuries can increase the risk of early-onset osteoarthritis. In addition, camaraderie could be developed among team members by encouraging athletes to work together and watch each other's technique when performing the ACL injury prevention training, similar to what was done by Pasanen et al. (2008).

Furthermore, as mentioned for the individual level, broadening the programs may help improve motivation and compliance. Instead of just an ACL injury prevention program, a program that encompasses prevention of other lower extremity injuries (e.g., ankle sprains, other

knee injuries, muscle strains) may have wider appeal to coaches, as the risk of number of injuries can be reduced with one training program. Studies such as LaBella et al. (2011), Pasanen et al., (2008), and Olsen et al. (2005) have indicated that this type of program can be effective.

Organizational level. The organizational level would focus on overcoming barriers to ACL injury prevention within schools and/or athletics clubs. One strategy at this level might be to develop and evaluate versions of injury prevention programs that are as brief as they can be without compromising effectiveness. Furthermore, the programs should be easy to implement (e.g., programs which are not difficult to learn, do not require a lot of equipment, and can be readily incorporated into a team's practice routine). Kiani et al. (2010) suggested that their study's high compliance rates may be because their program was easy to incorporate into practice, keeping extra time requirements low. Relatively-short, easy-to-use programs could help to overcome resistance from coaches that is based on a preventive program using up too much practice time.

Another way to reduce barriers to program effectiveness at the organizational level is to ensure that program facilitators receive quality preparation for leading the ACL injury prevention training programs. As stated earlier, the injury prevention programs are not likely to be successful if the exercises are not performed properly. Therefore, if coaches and/or athletes are leading the programs, it is important for them to obtain training that will adequately prepare them to correctly demonstrate and explain the exercises and monitor technique.

Community level. Reducing barriers to implementation at the community level could focus on institutions beyond the sports team. One possible strategy at this level is to develop moderately-priced videos of knee or lower-extremity injury prevention programs. A similar approach has already been utilized by the CDC in their "Heads Up: Concussion in Youth Sports"

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initiative (CDC, 2012). An affordable DVD that is readily available could help to overcome the barriers of prohibitive cost and low motivation to begin a preventive program. A media campaign to increase awareness of the injury prevention video would be beneficial, as well.

Another idea that could be considered at the community level is to solicit assistance from faculty and students at local universities which have programs such as athletic training, sports science, or physical therapy. Faculty members and students could volunteer to set up or assist with ACL injury prevention programs in local middle schools, high schools, or community sports leagues.

Policy level. The public policy level could focus on state and federal agencies, as well as the views of society regarding sports injury prevention. This level would likely involve policies put in place by high school and college athletic associations and state departments of education. Some possible policies that could reduce barriers to ACL injury prevention would be mandating that schools have a certified athletic trainer on staff, including sports injury prevention material in middle school physical education curricula, and requiring that some injury prevention exercises be included in school sports team training. To increase the willingness of legislators to make policy changes, it would be advantageous to develop evidence-based preventive training programs that effectively reduce risk for several lower extremity injuries.

In summary, we identified five potential barriers to implementation of ACL injury prevention programs: motivation, time requirements, skill requirements for program facilitators, compliance, and cost. We applied the socio-ecological model to suggest some possible strategies for overcoming these barriers. The issue of barriers to implementation of injury prevention training programs is an area that needs much more research.

Strengths and Limitations

One strength of the present study is that it considered a larger number of ACL injury prevention studies than did earlier meta-analyses (i.e., Hewett et al., 2006; Yoo et al., 2010; and Sadoghi et al., 2012). This is advantageous because it provides a more comprehensive picture of the effect of the injury prevention programs. Furthermore, another strength is that our study raises awareness of barriers to implementation of ACL injury prevention programs. Awareness of the barriers is beneficial because it can lead to more discussion and further research about barriers to implementation and how to overcome them. We hope this will lead to increased collaboration between researchers, clinicians, and coaches, as well as more widespread development and dissemination of injury prevention programs.

Our meta-analysis also has some limitations. As expected, the participants in the studies we analyzed tended to share particular characteristics (e.g., almost all females, mostly in their teens or twenties, played certain sports). Therefore, the study may not be generalizable to other populations. Additionally, our results may have publication bias due to some studies on this topic being unpublished. Furthermore, there appears to be little published literature that identifies barriers to implementation of injury prevention programs. Therefore, our description of barriers to implementation is likely to be incomplete, and the relative impact of each barrier is still unknown. However, identifying and overcoming barriers to program success will likely be necessary for ACL programs to be effective in reducing the overall incidence of ACL injuries in team sports.

Conclusions and Implications

In conclusion, we conducted a meta-analysis of neuromuscular training programs for ACL injury prevention in team sport athletes. We found that the data supported our hypothesis

that neuromuscular training programs were effective for preventing ACL injuries. In addition, we identified possible barriers to implementation of these programs and provided some suggestions of how to reduce these barriers.

The relationship between ACL injury prevention programs and widespread decrease in ACL injury incidence appears to be complex and multifactorial. Given the burden imposed by ACL injuries, including an increased risk of early onset osteoarthritis, we believe it would be beneficial to have greater dissemination and utilization of ACL injury prevention programs. Furthermore, there is a need to conduct further research on barriers to implementation of these training programs so that the programs can be more readily adopted by the target population. Additionally, because the amount of time allocated for a training program impacts both its effectiveness and implementation, determining the best duration of training for ACL injury prevention is another important area for further investigation.

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Appendix A: Communication with UMCIRB

From: "Conrad, Jason T" <CONRADJ@ECU.EDU>
Date: December 21, 2012, 2:14:02 PM EST
To: "Kulas, Anthony" <KULASA@ecu.edu>
Subject: RE: IRB requirement for meta analysis?

Sorry Dr. Kulas, you got lost in my emails. I talked to Norma a few days back and she said as this is not research the graduate student will be performing but rather analysis from public records of research conducted by other investigators, this would not need to have a completed IRB submission.

I hope you have a wonderful Christmas and a happy and safe New Year!

Jason

Jason T. Conrad, B.S.
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Phone: 252-744-3191
Fax: 252-744-2284

-----Original Message-----
From: Kulas, Anthony
Sent: Monday, December 10, 2012 5:31 PM
To: Conrad, Jason T
Subject: IRB requirement for meta analysis?

Jason, I have an IRB question for you. I have a graduate student who wants to perform a meta analysis for her thesis and I am asking you if I need to proceed with an IRB submission and approval beforehand. The meta analysis will only be performed using published research and the student will not be contacting the authors of the published research for more information to perform the meta analysis. Thus all data he student will need will be readily available in te published forms. Please advise on how I should proceed with IRB if his is needed.

Thank you for your time,

Tony

Anthony S. Kulas PhD, LAT, ATC

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Appendix B: Literature Search Process

Literature Search Conducted January 2013

Inclusion criteria:
ÉEvaluates a neuromuscular training program for injury prevention
ÉACL injury is an outcome measure
ÉIs a prospective study of team sport athletes
ÉIncludes a control
ÉThe number of non-contact ACL injuries is specified
ÉIs published in English
ÉIs published in a peer-reviewed journal

Keywords:
anterior cruciate ligament
injury
prevention

Search of PubMed via Medline: 580 articles retrieved
556 articles excluded ó are not trials to evaluate a neuromuscular training program for injury prevention
24 articles identified for further consideration

Excludedó ACL Injury Not an Outcome Measure	Excludedó Only a Description of Study Protocol, But No Results	Excludedó Not Published in Peer-Reviewed Journal (Course Lectures)	Excluded ó Not Published in English	Excludedó Number of Noncontact ACL Injuries Not Specified	Included in Primary Meta-Analysis
Noyes, 2012	Hagglund, 2009	Myklebust, 2007	Petersen, 2002	Walden, 2012	Gilchrist, 2008
Tsang, 2011		Hewett, 2007		Soderman, 2000	Pfeiffer, 2006
Lim, 2011				Heidt, 2000	Petersen, 2005
DiStefano, 2011				Caraffa, 1996	Mandelbaum, 2005
Vescovi, 2010					Myklebust, 2003
Ren, 2008					
Chappell, 2008					
Myer, 2006					
Myer, 2005					
Irmischer, 2004					
Wedderkopp,					

1999					

Secondhand search of articles and reference lists: 6 articles identified

Included in Primary Meta-Analysis	Included in Sensitivity Analysis 1: Studies Recording Contact and/or Noncontact ACL Injuries	Included in Sensitivity Analysis 2: RCTs
LaBella, 2011	Kiani, 2010	Steffen, 2008
Hewett, 1999	Steffen, 2008	Pasanen, 2008
Pasanen, 2008	Olsen, 2005	

Search of Cochrane Library: 4 articles retrieved

Excludedó ACL Injury Not an Outcome Measure
DiStefano, 2011
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LaBella, 2011	Walden, 2012	Walden, 2012
Gilchrist, 2008	LaBella, 2011	LaBella, 2011
Pasanen, 2008	Kiani, 2010	Gilchrist, 2008
Pfeiffer, 2006	Steffen, 2008	Steffen, 2008
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Mandelbaum, 2005	Pasanen, 2008	Olsen, 2005
Myklebust, 2003	Pfeiffer, 2006	Heidt, 2000
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