2017

THE EFFECT OF ONE-ON-ONE INTERVENTION IN ATHLETES WITH MULTIPLE RISK FACTORS FOR INJURY

Kathryn Schwartzkopf-Phifer
University of Kentucky, k8sp21@gmail.com
Digital Object Identifier: https://doi.org/10.13023/ETD.2017.442

STUDENT AGREEMENT:

I represent that my thesis or dissertation and abstract are my original work. Proper attribution has been given to all outside sources. I understand that I am solely responsible for obtaining any needed copyright permissions. I have obtained needed written permission statement(s) from the owner(s) of each third-party copyrighted matter to be included in my work, allowing electronic distribution (if such use is not permitted by the fair use doctrine) which will be submitted to UKnowledge as Additional File.

I hereby grant to The University of Kentucky and its agents the irrevocable, non-exclusive, and royalty-free license to archive and make accessible my work in whole or in part in all forms of media, now or hereafter known. I agree that the document mentioned above may be made available immediately for worldwide access unless an embargo applies.

I retain all other ownership rights to the copyright of my work. I also retain the right to use in future works (such as articles or books) all or part of my work. I understand that I am free to register the copyright to my work.

REVIEW, APPROVAL AND ACCEPTANCE

The document mentioned above has been reviewed and accepted by the student's advisor, on behalf of the advisory committee, and by the Director of Graduate Studies (DGS), on behalf of the program; we verify that this is the final, approved version of the student's thesis including all changes required by the advisory committee. The undersigned agree to abide by the statements above.

Kathryn Schwartzkopf-Phifer, Student

Dr. Tony English, Major Professor

Dr. Esther Dupont-Versteegden, Director of Graduate Studies

THE EFFECT OF ONE-ON-ONE INTERVENTION IN ATHLETES WITH MULTIPLE RISK FACTORS FOR INJURY

DISSERTATION

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the College of Health Sciences at the University of Kentucky

By

Kathryn Schwartzkopf-Phifer

Lexington, Kentucky

Co-Directors: Dr. Tony English, Professor of Physical Therapy

and Dr. Carl Mattacola, Professor of Athletic Training

Lexington, Kentucky

2017

ABSTRACT OF DISSERTATION

THE EFFECT OF ONE-ON-ONE INTERVENTION IN ATHLETES WITH MULTIPLE RISK FACTORS FOR INJURY

Background: Lower extremity (LE) musculoskeletal injuries in soccer players are extremely common. These injuries can result in many days of lost time in competition, severely impacting players and their respective teams. Implementation of group injury prevention programs has gained popularity due to time and cost-effectiveness. Though participation in group injury prevention programs has been successful at reducing injuries, programs often target a single injury and all players do not benefit from participation. Players with a greater number of risk factors are most likely to sustain an injury, and unfortunately, less likely to benefit from a group injury prevention program. The purpose of the proposed research is to determine if targeting these high risk players with one-on-one treatment will result in a reduction in the number of risk factors they possess.

Objectives: 1) Determine the effectiveness of one-on-one intervention for reducing the number of risk factors for LE musculoskeletal injury in soccer players with 3 or more risk factors; 2) Assess the effectiveness of matched interventions on reducing the magnitude of identified risk factors.

Hypothesis: Fifty percent or more of subjects receiving one-on-one intervention will have a reduction of ≥1 risk factor(s).

Design: Quasi-experimental pretest-posttest design.

Subjects: NCAA Division I men's and women's soccer players.

Methods: All subjects were screened for modifiable risk factors using a battery of tests which assessed mobility, asymmetry in fundamental movement pattern performance, neuromuscular control, and pain with movement. Players with ≥3 risk factors ("high risk") were placed in the treatment group and received one-on-one treatment from a physical therapist. An algorithm was created with interventions matched to specific deficits to determine the treatment each subject received. Subjects in the intervention group were treated twice per week for four weeks. Players with <3 risk factors ("low risk") were placed in the control group and did not receive one-on-one intervention.

Analysis: The primary outcome measure was proportion of treatment successes, defined as a reduction of ≥1 risk factor(s). Secondary outcomes included analysis of within group and between group differences.

Results: Thirteen subjects were treated with one-on-one intervention, with twelve having a reduction of at least 1 risk factor at posttest. The proportion of treatment successes in

the intervention group was 0.923 (95%CI 0.640-0.998). The proportion of high risk subjects that became low risk at posttest was 0.846, which was statistically significant (p=0.003). Within group differences were noted in active straight leg raise (left; p=0.017), hip external rotation (right, p=0.000; left, p=0.001) thoracic spine rotation (left; p=0.026), and upper quarter neuromuscular control measures (left inferolateral reach, p=0.003; left composite, p=0.016). A statistically significant between group difference was noted in risk factor change from pretest to posttest (p=0.002), with the median risk factor change in the intervention group and control group being -3 and -1, respectively.
Conclusion: Utilizing one-on-one interventions designed to target evidence-based risk factors is an effective strategy to reduce LE musculoskeletal injury risk factors in high risk individuals.
Key words: injury risk, injury prevention, soccer

____Kathryn Schwartzkopf-Phifer____
Student Name
____________November 21, 2017____________
Date

THE EFFECT OF ONE-ON-ONE INTERVENTION IN ATHLETES

WITH MULTIPLE RISK FACTORS FOR INJURY

By

Kathryn Schwartzkopf-Phifer

________Dr. Tony English___
Co-Director of Dissertation

________Dr. Carl Mattacola__
Co-Director of Dissertation

Dr. Esther Dupont-Versteedgen
Director of Graduate Studies

November 19, 2017

DEDICATION

“Our deepest fear is not that we are inadequate. Our deepest fear is that we are powerful beyond measure. It is our light, not our darkness that most frightens us…Your playing small does not serve the world. There is nothing enlightened about shrinking so that other people will not feel insecure around you. We are all meant to shine, as children do. We were born to make manifest the glory of God that is within us. It is not just in some of us; it is in everyone and as we let our own light shine, we unconsciously give others permission to do the same. As we are liberated from our own fear, our presence automatically liberates others.”

-Marianne Williamson

I dedicate this dissertation to my babies—Calvin, Zoe and Eric: I hope I’ve shown you that it’s okay to let your light shine.

ACKNOWLEDGEMENTS

To my committee, Dr. Tony English, Dr. Carl Mattacola, Dr. Emily Dressler, and Dr. Kyle Kiesel: There aren't many doctoral programs that would provide the kind of flexibility that a working mom of 3 needs to finish her degree. Too many times women are forced to wait until their kids are grown to pursue their education; or worse, choose between a family and a career. Because of your support, I didn't have to do either. Thank you for helping to make my dreams a reality.

To Mom & Dad: I could fill this dissertation with all the reasons I'm thankful you are my parents, and it still wouldn't be enough. Above all else though, thank you for teaching me to never be afraid of working hard.

To Rachel: I spent most of my childhood trying to be exactly like you. Turns out, I'm spending my adulthood doing the same. Thank you for inspiring me to pursue teaching (and for sending Harry Potter memes when I needed a laugh).

To Jessi: Your never-ending praise and encouragement has meant more than you know.

To Dr. Phil Plisky: Thank you for never showing me the path, but instead, helping me to believe I could find it for myself.

To Dr. Tink Martin: I am forever grateful for your advice, encouragement, and hugs.

To Dr. Lisa Phifer, Dr. Kyle Matsel, and Dr. Bethany Huebner: Thank you for being so supportive and so willing to proofread my work. I couldn't have done this without you.

To Craig: Pursing a PhD when you have 3 kids under 6 and work full time while your husband opens his own business sounds insane. It could have been a disaster; admittedly, it was at times. You've been far more understanding than I deserve. Thank you for your patience and encouragement.

To my babies, Calvin, Zoe and Eric: You are all far too little to understand what mommy has been doing, but you've always known what I needed. Thank you for telling me to play with you. Thank you for telling me to read with you. Thank you for the extra hugs and kisses. And thank you for (sometimes) letting me sleep.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1: Introduction

Injuries to the lower extremity are common in collegiate soccer players, with injuries to the ankle, knee and thigh having the highest incidence.(1) While evidence suggests that overall injury rates in soccer players have declined in recent years, non-contact injuries, which are largely preventable, have increased and are occurring at a rate of 2.855 per 1000 athlete-exposures (AE). Additionally, non-contact injuries in male soccer players have increased from 2.731 per 1000 AE from 1990-1996, to 2.988 per 1000 AE from 2004-2009.(1) Finally long term injuries, or those accounting for time lost from competition of ≥7 days, are also on the rise; long term injury rates from 2004-2009 were 2.986 per 1000 AE compared to 2.239 per 1000 AE from 1990-1996.(1) This evidence suggests that overall injury prevention efforts have been successful, however improvements can be still be made.

Modifiable risk factors are those that respond favorably to common rehabilitation techniques, and researchers have identified many risk factors for musculoskeletal injuries in soccer players. The volume of modifiable risk factors presents a challenge to clinicians and coaching staffs, as it is not feasible to test for all the identified risk factors that have been reported in the literature. To streamline injury preventative efforts, many clinicians and coaches have opted to develop general programs that intervene with risk factors for a specific injury. For example, to address risk factors associated with anterior cruciate ligament (ACL) tears, programs such as Sportsmetrics™ were created. The Sportsmetrics™ approach consists of a standardized exercise program to address lower extremity strength and flexibility, core neuromuscular control, and agility. A recent meta-analysis concluded that participation in an injury prevention program leads to a statistically significant reduction in ACL tears.(2) While reducing the number of ACL tears is beneficial, these programs do not document other injuries, leaving athletes vulnerable to injury in adjacent areas of the lower extremity. To achieve the greatest injury reduction rates, injury prevention programs should take a more comprehensive approach, taking into account risk factors associated with multiple lower extremity (LE) injuries.

A battery of tests, examining risk factors common to several lower extremity injuries, may be a solution. Mobility deficits, particularly in the hip and ankle, have been identified as risk factors for LE injury. Verrall et al found that hip external rotation (ER) range of motion (ROM) was significantly lower in athletes that went on to develop groin pain.(3) In a recent systematic review, de Noronha determined that ankle dorsiflexion was a strong predictor for future ankle injury; individuals with ankle dorsiflexion ROM measures of ≤34 degrees were five times more likely to have an ankle injury compared to those with ≥45 degrees or more.(4) Not only has total ankle dorsiflexion ROM shown a relationship to injury, but so has asymmetry in available motion compared to the opposite side. In a large study of warrior athletes, Teyhen et al determined that an asymmetry of ≥6.5 degrees of ankle dorsiflexion led to an odds ratio (OR) of 4.10 (95% CI 1.40-11.70) for future musculoskeletal injury.(5) Asymmetry in fundamental movement patterns has also been associated with injury risk. At least one asymmetry in hurdle stepping, lunging, active straight leg raising, or quadruped diagonal reaching pattern was associated with an OR of 1.80 (95% CI 1.11-2.74) for a time-loss musculoskeletal injury in American football players.(6) Mokha et al determined that asymmetry or poor performance on the aforementioned movement patterns had an OR of 5.27 (95% CI 1.93-14.40) for future musculoskeletal injury.(7) Asymmetries in dynamic neuromuscular control, defined as >4 cm difference in reach distance using the Lower Quarter Y Balance Test (YBT-LQ), has been associated with increased odds for LE injury. Anterior reach asymmetry or low performance in the anterior reach direction has been shown to increase risk for LE injury in active populations with ORs of 2.30 (95%CI 1.20-4.20)(8) and 2.84 (95%CI 1.58-5.10) (9), respectively. Low composite score on the YBT-LQ has also been associated with increased risk of injury in athletic populations.(8) Finally, presence of pain during movement testing also increases risk for injury. In a population of Army soldiers, the presence of pain with performance of fundamental patterns led to ORs ranging from 1.50 (95%CI 1.14-1.99; squat) up to 3.51 (95%CI 2.05-6.03; hurdle stepping) for future musculoskeletal injury.(10)

Deficits in neuromuscular control of the core has also been identified as a risk factor for LE injuries. Zazulak et al identified an association between knee injuries and increased trunk displacement measures following an unanticipated trunk perturbation in collegiate athletes.(11) Additionally, Wilkerson et al reported ORs for core or lower extremity strain of up to 4.17 (95%CI 1.52-11.45) in American football players with decreased trunk flexion hold times (<161 seconds).(12) Though deficits in trunk or core neuromuscular control has been identified as a risk factor for LE injuries, limited attention has been paid to trunk mobility. To date, no study has examined the relationship between thoracic spine mobility and LE injury. The role of the trunk during walking and running tasks has long been documented biomechanically.(13) Recently researchers have observed that trunk mobility is increased in subjects with chronic ankle instability during lower limb reaching tasks.(14) Given that peripheral deficits can influence trunk mechanics, it is plausible that limitations in thoracic mobility could influence LE mechanics thereby contributing to overall injury risk.

It has been suggested that injury rates in collegiate soccer players have decreased in recent years due to the growing popularity of group injury prevention programs.(1) Fèdèration Internationale de Football Association (FIFA) 11+ contains dynamic hip mobility, eccentric hamstring and core neuromuscular control exercises, as well as agility drills. The program also focuses on avoidance of valgus collapse during running and jumping activities. Current evidence suggests that performance of FIFA 11+, 1-2 times per week can significantly reduce injury rates by up to 70%.(15) Programs like FIFA 11+ are an attractive option for injury prevention efforts, as all players are performing the same exercises as part of a standardized warm up prior to practices or games under the supervision of their coaches. With a time commitment of 15-20 minutes, group programs are a cost-effective approach to decreasing injuries. Unfortunately individual athletes will differ on presence of risk factors and deficits, all in varying degrees of severity, leaving some to reap the benefits of consistent performance of an injury prevention program while others do not. Huebner et al concluded that athletes in the highest risk category, or those with the greatest number of risk factors, were less likely to respond to a group injury prevention program consisting of dynamic warm up, eccentric and core neuromuscular control exercises, and agility and jump training.(16) This is concerning, as recent evidence suggests a somewhat linear relationship in regards to number of risk factors and risk for future injury. In a population of warrior athletes, Teyhen et al determined that the odds of sustaining a LE injury were low if an individual had 1 or 2 risk factors (OR 0.9- 95%CI 0.40-2.40, and 1.90 95% CI 1.00-3.50, respectively).(5) Odds ratios increased significantly in the presence of 3-5 risk factors though, with ORs ranging from 4.60-6.70.(5) Additionally, collegiate athletes with the greatest number of risk factors were 17.6 times (95%CI 2.50-123.60) more likely to sustain a non-contact LE injury than those athletes with the least number of risk factors.(17) Taken collectively, these results suggest that athletes with a higher number of risk factor are therefore at the highest risk for injury, and may benefit from a more individualized approach to decrease risk.

Purpose

Despite the success of injury prevention efforts in recent years, there are many athletes who are unsuccessful in group programs due to the volume of risk factors they possess. Therefore, it is imperative to create a battery of tests which identifies the modifiable risk factors common to multiple LE injuries. Once these risk factors have been identified and measured, effective rehabilitation interventions should be matched to them to target those athletes at the greatest risk for injury. The purpose of this study is to determine if one-on-one intervention for collegiate soccer players with ≥3 modifiable injury risk factors is capable of significantly reducing the number of risk factors each player possesses.

Objectives

Primary Objective: To determine the effectiveness of one-on-one intervention in reducing the number of risk factors for musculoskeletal injury in collegiate soccer players with ≥3 risk factors.

Hypothesis: Fifty percent or more of players treated with one-on-one interventions will have a reduction of ≥1 risk factors.

Secondary Objective: To assess the effectiveness of matched interventions on the magnitude of identified risk factors.

Hypothesis: Players treated with one-on-one interventions will have a greater magnitude of change in identified risk factors compared to controls.

Operational Definitions

Modifiable Risk Factors: A measurable, movement based factor that has been shown to increase risk for musculoskeletal injury, yet responds favorably to common rehabilitation interventions.

Time-Loss Injury: Any impairment, acute or chronic, that produces pain or damage to a muscle, tendon, ligament or bone which results in the athlete missing a scheduled workout, practice, or competition.

Odds Ratio (OR): The ratio of the odds of sustaining of an injury in individuals that are exposed to a risk factor(s) to the odds of developing an injury in individuals that are unexposed to a risk factor(s). Odds ratios are calculated using a 2x2 table with associated 95% confidence intervals. If the OR is >1, the factor increases the odds of sustaining an injury. If the OR is <1, the factor decreases the odds of sustaining an injury (and is therefore protective). If the confidence interval contains the value of 1, the relationship is not significant.

Relative Risk (RR): The ratio of exposure to a risk factor(s) in individuals that have sustained an injury to individuals that were unexposed to a risk factor(s) and did not sustain an injury. Relative risk is calculated using a 2x2 table with associated 95% confidence intervals. If the RR is >1, the factor increases the risk of sustaining an injury. If the RR is <1, the factor decreases the risk of sustaining an injury (and is therefore protective). If the confidence interval contains the value of 1, the relationship is not significant.

Lower Extremity Injury: Any physical report of discomfort or dysfunction involving a muscle, tendon, ligament, or bone of the pelvis, thigh or lower leg resulting in time lost to competition.

Delimitations

1. All subjects enrolled in the study continued participation in team workouts, practices, and scrimmages without restriction for the purposes of reproducing the

sport conditions and requirements. This unrestricted participation provided a greater understanding of the impact a soccer season has on clinical interventions and injury prevention efforts.

2. All subjects received treatment based on the algorithm created, according to which risk factors they possessed.
3. Risk factors were determined using field-based measurements and tests.

Limitations

1. All subjects were collegiate soccer players at a division I university.
2. One-on-one session length was not controlled, though sessions typically lasted 20-30 minutes.
3. Compliance with independent performance of home exercises was poorly documented.
4. Risk factors were not weighted according to strength of evidence.
5. Long term follow up was not feasible.

Chapter 2: Systematic Review

The purposes of this review are to 1) identify modifiable risk factors specific to soccer for development of a field-based risk factor screen and 2) identify rehabilitation techniques effective at improving those risk factors.

Introduction

Soccer is the most popular sport in the world, with an estimated 265 million people participating worldwide.(18) Due to sport requirements and the contact nature of the soccer, time-loss musculoskeletal injuries are common. The vast majority of soccer injuries occur in the LE; injuries to the ankle, knee, and thigh have the highest prevalence.(1) It is estimated that an injury to a top player can cost a football (soccer) club up to $500,000 (19), and can incur up to 752 days of time lost (20), thus making injuries a personal and financial hardship. Therefore, it would be beneficial to identify risk factors that contribute to musculoskeletal injuries and provide the appropriate intervention to mitigate these effects.

Though research has identified many modifiable risk factors, translation into clinical practice has been a challenge. Some tests use equipment, such as a Biodex or three dimensional movement analysis, and are not readily available for most clinicians. Additionally the sheer number of risk factors identified in the literature, all with varying strength of association to injury, makes it impossible to utilize all in a screening process. Read et al suggests "a systematic model" where " each risk factor is linked to a neuromuscular screening assessment and target exercises are then selected to improve relevant neuromuscular control deficits."(21) In an effort to make these links, many researchers and clinicians have narrowed prevention efforts to a single injury in a given sport. For example, the Sportsmetrics™ program was designed to address multiple factors that contribute to ACL injury, one of the most prevalent and severe knee injuries in soccer. A recent meta-analysis shows that participation in an injury prevention program leads to a statistically significant reduction in ACL tears.(2) However the included studies fail to take into account other injuries affecting the LE. While a reduction in ACL tears is beneficial, athletes remain vulnerable to other injuries. Ideally, injury prevention programs would offer a more comprehensive approach.

Development of a screening program that considers multiple risk factors for all sports may not be feasible. However, identification of sport-specific risk factors common to all LE injuries could be beneficial when developing an expedient screening program. The ability to quickly identify individuals at risk for a number of injuries would allow rehabilitation providers to create individualized prevention programs that have a broader effect on injury reduction. Therefore, the purpose of this review is to identify modifiable risk factors for all LE injuries in soccer players to aid in the development of comprehensive injury prevention programs. It is hypothesized that previous history of injury, as well as deficits in dynamic neuromuscular control and ankle dorsiflexion ROM will be strong predictors of future injury in soccer players.

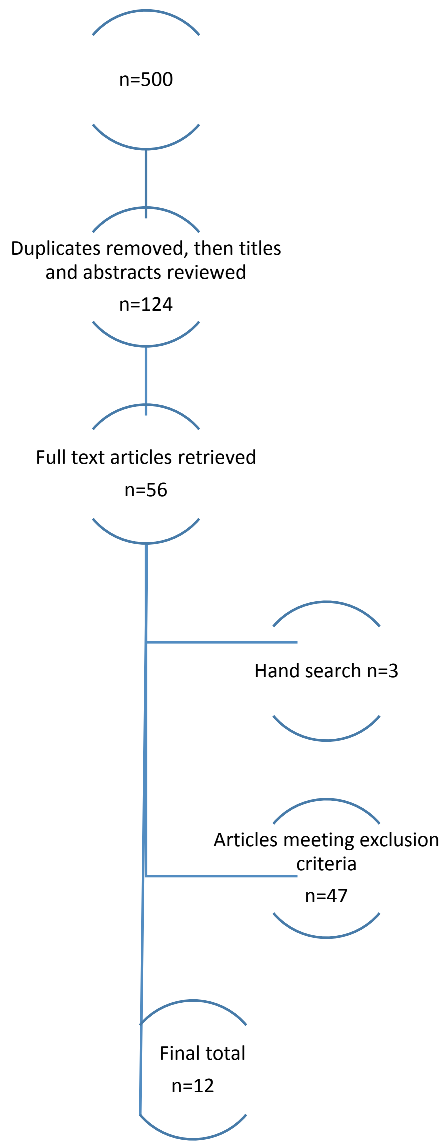
Methodology

Databases including PubMed, SportDiscus, Medline, and CINAHL were searched in January of 2017. Search strategy and results are listed in Table 2.1 (continued). Titles and abstracts of articles were reviewed and full text articles were retrieved based on inclusion criteria (see Figure 2.1, continued). Criteria for inclusion was any prospective injury study on soccer athletes published from 2007 to January 2017. Articles were excluded if they included athletes from other sports. Abstracts from professional conferences and literature or systematic reviews were also excluded. Finally, studies that were retrospective or epidemiologic in nature were also excluded.

Table 2.1. Results of search by database.

	Terms	Boolean Operator	Results by Database			
			CINAHL	MEDLINE	SPORTDISCUS	PUBMED
S1	Hip Knee Ankle Groin Hamstring	OR	46,273	149,149	40,814	141,845
S2	Injury Risk Predict*	OR	377,109	1,868,923	113,419	2,049,710
S3	Soccer Football	OR	4,506	9,071	100,783	9,332
S4	Prospective Cohort	OR	161,284	569,082	15,969	639,870
S5	S1, S2, S3, S4	AND	180	282	204	305
S6	S5, Australian Gaelic Prevent*	AND, NOT	101	144	100	155

Figure 2.1. Search results.



Quality of each study was determined using an index designed to assess observational studies. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement is a 22 item appraisal tool, assessing areas such as data analysis, participant information, bias and study design (see Appendix A).(22) The STROBE was selected and modified to allow for direct comparison of cohort studies. Each item on the STROBE was given a value of one, for a maximum score of 22.

Modifiable Risk Factors

A modifiable risk factor was defined as a measurable movement based factor that responds favorably to common rehabilitation interventions. History of previous injury has historically been considered the strongest predictor of future injury. Though it is a non-modifiable factor, results of injury history were included in this review to determine if current research is consistent with this belief. Details of each included study are presented in Table 2.2 (continued) and findings are summarized below.

Table 2.2. Summary of included studies.

Author	Subjects	Modifiable risk factors	Measurements	Reliability	Main findings	STROBE
Bradley et al(23)	35 elite males	ROM	Hip and knee flexion and extension, ankle plantarflexion and dorsiflexion using 2D video analysis measured preseason	ICC: hip=0.92, knee=0.95, ankle 0.91*	Statistically significant difference in hip flexor ROM (p=0.03) and knee flexor ROM (p=0.01) between injured and uninjured players	12
Clausen et al(24)	326 U18 females	Self-reported previous injury and function	KOOS (<80 points)	NR	*Previous injury*: RR 3.64 (95% CI 1.73-7.66) *KOOS Subscales*: ADL=RR 5.00 (95% CI 1.53-16.38); Sports=RR 2.23 95% CI 1.01-4.93); QOL=RR 3.01 (95% CI 1.13-8.00)	15
Engebretsen et al(25)	508 amateur males	Previous injury, neuromuscular control, foot posture, ROM, self-reported function	*Neuromuscular control*: Eyes open and closed on stable surface and foam pad, scored on a scale of 1-5 *Foot posture*: visual observation *ROM*: supination, pronation, dorsiflexion* *Function*: FAOS	Neuromuscular control (interobserver) k=.40 (stable surface), k=.19 foam pad	Previous ankle injury: OR 1.23 (95% CI 1.06-1.41)	17

Engebretsen et al(26)	508 amateur males	Previous injury, pain, ROM, strength, function	*Pain*: during palpation, ROM, and functional testing; *ROM*: Hip* *Strength*: Isometric hip adduction using HHD *Function*: counter movement jump, 40m sprint, GrOS	NR	*Previous groin injury*: OR 2.60 (95% CI 1.10-6.11); *Adductor weakness*: OR 4.28 (95% CI 1.31-14.0) *40m sprint:* OR 2.03 (95% CI 1.06-3.88)	18
Engebretsen et al(27)	508 amateur males	Previous injury, ROM, function	*ROM*: knee flexion and extension* *Function*: countermovement jump, 40m sprint, KOOS	NR	KOOS Subscale Pain: OR 1.26 (95% CI 1.03-1.55)	17
Engebretsen et al(28)	508 amateur males	Previous injury, strength, ROM, function	*Strength*: Nordic hamstring exercise < 30 degrees *ROM*: Hip* *Function*: countermovement jump, 40m sprint, HaOS	Intertest reliability of Nordic hamstring exercise k=.24	Previous hamstring injury: OR 2.19 (95% CI 1.19-4.03)	16
Fousekis et al(29)	100 professionals	Previous injury, strength, ROM, proprioception	*Strength*: Isokinetic at 60, 180, and 300 degrees/sec *ROM*: quadriceps, hamstrings, ankle plantarflexors* *Proprioception*: kinesthetic stabilometer	NR	*Previous hamstring injury*: OR 0.15 (95% CI 0.03-0.79) *Eccentric hamstring strength asymmetry* (>15%): OR 3.88 (95% CI 1.13-13.23) for future hamstring injury	18

Gonell et al(30)	74 (34 professional, 40 amateur) males	Dynamic neuromuscular control	Y Balance Test	NR	Posteromedial reach asymmetry of ≥4cm: OR 3.86 (95% CI 1.46-10.95) for non-contact injuries	17
Henry et al(31)	210 amateur males	ROM, power, neuromuscular control, function	*ROM*: WBLT *Power*: Vertical jump <30 W/kg *Neuromuscular control*: computerized wobble board *Function*: Incline squat	WBLT: ICC ≥ 0.97(32) Intertest reliability: Incline squat, ICC=0.90-0.96; Computerized wobble board, ICC=0.55-0.71. WBLT and vertical jump NR.	*Vertical jump*: OR 9.20 (95% CI 1.13-75.09) *Neuromuscular control*: OR 0.43 (95% CI 0.21-0.89)	15
Nilstad et al(33)	173 elite females	Previous injury, strength, dynamic neuromuscular control, function	*Strength*: Isokinetic at 60 degrees/second, 1RM leg press, hip abduction using HHD *Neuromuscular control*: SEBT *Function*: Vertical drop jump landing using 3D motion analysis	Vertical drop jump ICC=0.62-0.99(34)	*Previous knee injury*: OR 3.57 (95% CI 1.27-9.99) for lower leg/foot injuries; *Vertical drop jump landing*: OR 0.64 (95% CI 0.41-1.00) for future ankle injuries	15

Steffen et al(35)	1430 U 17 females	Previous injury, self-reported function	FAOS, KOOS, GrOS, HaOS	NR	*Previous injury*: History of ankle injury RR 1.20 (95% CI 1.10-1.30) for future ankle injury *History of knee injury*: RR 1.40 (95% CI 1.20-1.60) for future knee injury *History of groin injury*:RR 1.60 (95% CI 1.20-2.10) for future groin injury *Low function*: Low FAOS=RR 1.70 (95% CI 1.10-2.70) for future ankle injury; Low=KOOS RR 3.20 (95% CI 1.80-5.70) for future knee injury	18
Van Dyk et al(36)	614 elite males	Strength	Isokinetic at 60 and 300 degrees/second	NR	Body weight adjusted concentric quadriceps at 60 degrees/second: OR 1.41 (95% CI 1.03-1.92); Body weight adjusted eccentric hamstring at 60 degrees/sec: OR 1.37 (95% CI 1.01-1.85)	17

Abbreviations: Range of motion (ROM); Not report (NR); Foot and Ankle Outcome Score (FAOS); Knee and Osteoarthritis Outcome Score (KOOS); Groin Outcome Score (GrOS); Hamstring Outcome Score (HaOS); Odds Ratio (OR); Relative Risk (RR); Quality of Life (QOL); Handheld dynamometer (HHD); Weight Bearing Lunge Test (WBLT); Star Excursion Balance Test (SEBT)
*Additional information regarding measurement tool and subject positioning was unavailable.

Results

Previous injury

Six studies identified history of previous injury as predictive of future injury. History of ankle, hamstring and groin injury was predictive of future ankle, hamstring and groin injury, respectively, with ORs ranging from 2.19-2.60.(25, 26, 28) Steffen et al reported that history of previous injury to the ankle, knee or groin predicted new injuries to these same respective sites, with ORs ranging from 1.20-1.60.(35) Nilstad reported that a history of previous knee injury resulted in an OR of 3.57 (95% CI 1.27-9.99) for future lower leg or foot injuries.(33) Finally, Clausen reported that players with a history of previous injury had an OR of 3.59 (95%CI 1.73–7.46) for future injury.(24)

Conversely, Engebretson et al did not find a relationship between previous knee injury and future knee injury.(27) Steffen et al (35) did not find a statistically significant increase in hamstring injuries between those with and without a history of hamstring injury, while Fousekis et al (29) found that having a history of previous hamstring injury was protective of future hamstring injuries (OR 0.15 95%CI=0.03-0.79). While Nilstad et al found an association with previous knee injuries and future lower leg/foot injuries, all other previous injuries did not show a statistically significant OR. Previous ACL injury did not predict LE injury (OR 1.55, 95% CI 0.42-5.68), previous hamstring injury did not predict thigh injury (OR 1.35, 95% CI 0.42-4.38), and finally, previous ankle injury and previous ACL injury did not predict knee injury (OR 1.46 95% CI 0.64-3.31 and OR 3.30 95% CI 0.82-13.3, respectively).(33)

Five studies determined that history of previous injury predicted future injury, two found mixed results, one did not find an association, and one found a protective association. All studies had similar quality ratings on the STROBE, ranging from 15-18.

Pain and Self-Reported Function

Only one study reported pain during examination with an OR 2.90, however the 95% CI was 0.55-15.20, indicating a non-significant finding.(26) Other studies documented presence of pain using self-reported outcome tools. Pain reported on the pain subscale of both the Foot and Ankle Outcome Score (FAOS) and the Knee and Osteoarthritis Outcome Score (KOOS) lead to a relative risk (RR) of 1.22 (95%CI 1.07-1.40) and 1.50 (95%CI 1.29-1.75), respectively.(35) Additionally, Steffen et al found that all other subscales (symptoms, sport, activities of daily living, quality of life) as well as total score on both the FAOS and KOOS were associated with greater odds for injury, with ORs ranging from 1.21-1.72.(35) Clausen et al also reported that athletes scoring below 80 on the activities of daily living, sports/recreation, and quality of life subscales on the KOOS had a RR of 5.00 (95% CI 1.53–16.38), 2.23, (95% CI 1.01–4.91), and 3.01 (95% CI 1.13–8.00), respectively.(24)

Alternatively, Engebretsen et al also used to FAOS to determine self-reported function and did not find an association with future injury.(25) The remaining studies by Engebretsen et al also did not show an association between self-reported function and future injury using the Groin Outcome Score (GrOS), Hamstring Outcome Score (HaOS) and KOOS.(26-28) Therefore, pain was associated with injury in two studies while self-reported function did not show an association to injury in four studies. All studies had similar quality scores, ranging from 15-18.

Range of Motion/Flexibility

Range of motion or flexibility measurements were the most commonly assessed factors in the studies reviewed, with seven of twelve measuring mobility of at least one joint or muscle group. Only two found that limited ROM or flexibility was predictive of future injuries. Using video analysis and reflective body markers, Bradley et al(23) determined that limitations in hip flexor mobility ($p=.03$) and knee flexor mobility ($p<.01$) were predictive of future muscle strains. Engebretson et al(26) determined limited hip ER, as determined in a standard clinical exam, was predictive of future groin injuries.

Bradley et al also measured hip extension and knee extension, as well as ankle plantarflexion and dorsiflexion and did not identify a statistically significant difference in mobility between those soccer players that did not incur an injury and those that did.(23) The remaining measurements in Engebretsen et al's studies did not find an association with ROM and injury, which included measurements of foot pronation and supination, ankle dorsiflexion, hamstring flexibility, and hip ROM.(25, 27, 28) Plantarflexor and hamstring flexibility, as well as quadriceps, was also assessed by Fousekis et al who similarly found no association to injury.(29) Finally dorsiflexion, as measured by the weight bearing lunge test (WBLT), did not predict future injury in Henry et al's study.(31)

Of the seven studies measuring ROM or flexibility only two found an association to injury, one of which had the lowest quality score (Bradley et al) of all studies included in this review. The remaining five articles, with quality scores ranging from 15-18, did not find an association between various measurements of LE ROM or flexibility and injury.

Strength

Strength measurements were collected in five of the studies reviewed. Engebretsen et al found that players with adductor weakness, assessed via handheld dynamometer (HHD) with the subject in supine and testing leg extended, had an OR of 4.28 (95%CI 1.31-14.0) for future groin injury.(26) Isokinetic measurements assessing hamstring to quadriceps strength ratios (HQR) were used in three of the included studies. Fousekis et al found that eccentric hamstring asymmetry, defined as a difference of 15% or greater between legs, led to an OR of 3.88 (95%CI 1.13-13.23).(29) Finally, body weight adjusted isokinetic testing of the quadriceps and hamstrings predicted future hamstring injuries with an OR of 1.41 (95%CI 1.03-1.92) and 1.37 (95%CI 1.01-1.85), respectively.(36)

The final study using HQR did not find an association between low ratios and LE injury.(33) Additional strength measures of one repetition maximum (1RM) on a leg press and hip abduction using a HHD were also unable to predict future LE injury.(33) Additionally, the Nordic hamstring exercise, a popular eccentric training exercise where subjects slowly lower themselves to a prone position from tall kneeling, was used as an assessment of eccentric hamstring strength in one study. Using a cut off of 30 degrees from vertical, Engebretsen et al (28) did not find an association between eccentric hamstring "weakness" on the Nordic hamstring exercise and future hamstring injury.

Strength testing using HHD and isokinetics predicted future injury in three studies, with STROBE scores ranging from 17-18. The final two studies had lower quality scores, ranging from 15-16, and did not show an association between strength measures and injury.

Neuromuscular Control and Proprioception

Neuromuscular control was also assessed in five of the included studies, with only two finding a significant relationship. Henry et al (31) assessed neuromuscular control using a "computer-interfaced wobble board", where players were asked to stand on a circular disk and keep the edges from touching the force plate for two, 20 second trials. Players who were able to maintain balance longer had an OR of 0.43 (95%CI

0.21-0.89), indicating that better neuromuscular control was protective of future injury.(31)

Two studies used the Star Excursion Balance Test (SEBT) to measure dynamic neuromuscular control with mixed results. Gonell et al (30) found that athletes with a posteromedial reach asymmetry of ≥4cm had an OR of 3.86 (95% CI 1.46-10.95) for future LE injury, whereas Nilstad et al (33) did not find an association between performance on the SEBT and injuries to the thigh, knee, ankle or lower leg.

Finally, Engebretsen et al and Fousekis et al did not find that neuromuscular control or proprioception, respectively, was predictive of future injuries.(25, 29) Engebretsen et al(25) measured single leg balance on a scale of 1-5 and Fousekis et al (29) measured proprioception using a kinesthetic stabiliometer (Prokin-200). Only 2 studies, with quality scores of 15 (Henry et al) and 17 (Gonell et al), found an association between neuromuscular control and injury. The remaining 3 studies, of similar quality, did not find an association to injury.

Other Measures

An additional movement based measure included in one study was the incline squat.(31) Subjects performed a single leg squat while standing on a 10 degree wedge placing them in dorsiflexion. The angle of maximum dorsiflexion was measured using a two dimensional video analysis. Ultimately this test, which the authors considered a measure of lower limb stability, was eliminated from the final model due to its strength of correlation with the WBLT ($r = 0.566$).(31)

Four studies used a countermovement jump (26-28, 31) and three used a 40 meter (m) sprint to determine association with injury.(26-28) The countermovement jump requires subjects to begin in standing with knees extended, then squat to 90 degrees knee flexion before jumping vertically as high as possible. The best of three trials was used for final analysis, though none of Engebretsen et al's studies showed an association to injury. An additional study used a single leg countermovement jump to determine the relationship between power and injury. Using a cut off of 30 W/kg, athletes scoring below this cut point had an OR of 9.20 (95% CI 1.13-75.09).(31) The 40m sprint was performed once using time sensors. Only one study found an association between performance and groin injury.(26)

Finally Nilstad et al measured knee valgus angles during a drop jump landing using a three dimensional motion analysis.(33) Greater knee valgus angles were not associated with knee or thigh injuries, though the OR for future ankle injuries was 0.64 (95% CI 0.41-1.00).(33) This indicates that greater knee valgus angles may have a protective effect on ankle injuries.

All studies using other measures had STROBE scores ranging from 15-18. Of the four studies using a countermovement jump, only one found an association to injury. Sprint time was associated with injury in only one study. Additional measures of incline squat, and knee valgus angles during a drop jump landing did not have an association to injury, however the latter suggests greater angles may be protective of ankle injuries.

Discussion

Risk factors

History of previous injury has been widely accepted as the strongest predictor of future injury. This long held notion is largely supported in the articles reviewed. Interestingly, Fousekis et al (29) found that previous hamstring injury was protective of future hamstring injury. Subjects were excluded if they had an injury within the previous six months, leaving several months for athletes to potentially recover from less severe injuries. This notion is supported by Engebretsen et al (25), who reported the odds of sustaining a future injury were highest during the six months following initial injury (OR=2.81 [95%CI 1.42-5.54]), and gradually decreased as time progressed. Steffen et al (35) and Engebretsen et al (27) did not find history of previous injury to be predictive of future injury. Authors have hypothesized that previous injury is such a strong predictor of future injury due to incomplete rehabilitation.(37) However, it is possible that those athletes that have been injured received adequate rehabilitation and were "recovered". Chorba et al (38) found that female collegiate athletes, including soccer players, with a history of ACL tear scored higher on the Functional Movement Screen (FMS)—a screen of fundamental movement patterns where lower performance is associated with increased injury risk—than those without ACL tear.(39) The authors concluded that scores were higher in subjects with previous ACL tear due to "emphasis on lower extremity strength and neuromuscular control" during rehabilitation after ACL reconstruction(38), suggesting that appropriate rehabilitation can mitigate the effects of history of previous injury.

Movements eliciting pain during clinical examination were only documented in one study. Engebretsen et al (26) described pain with hip ER as a "potential independent risk factor" for future injury, as this factor was found to be non-significant in the multivariate model. Painful movement has been identified as a risk factor for future injury in other studies in analogous populations.(5, 10) Additionally, self-reported pain and limited function on the FAOS and KOOS served as a predictor of future injury.(24, 27, 35) Taken collectively, these findings indicate that current pain with movement could be a predictor of future injury and should be considered when screening players for risk factors.

Conversely, self-reported function using the GrOS and HaOS were not shown to have an association to injury. These outcome tools were developed from the KOOS, which has shown acceptable reliability and validity.(40) Reliability of the GrOS and HaOS has not been reported, thus making it impossible to validate as an appropriate measure of function or predictor of injury. Though self-reported function may be a tempting alternative to a physical screening process for busy clinicians, utilization of these outcomes tools in isolation should be cautioned until reliability and validity can be established.

Decreased hamstring flexibility was examined as a predictor of future hamstring injury with mixed results, which is consistent with other authors.(41) Though limited hip ER was discussed as a risk factor for future groin injury, given the strong correlation between limited ROM and pain during hip ER (P=.02), only pain remained in the final analysis.(26) Due to the exclusion of this variable, “limited” hip ER was not further defined. Additional measurements of hip, knee and foot mobility were not found to be predictive of injury, however descriptions of measurement methods were also lacking. Several tools for measuring ROM exist and position of the subject can vary substantially, making it difficult to draw conclusions on the value of ROM measurements in the prediction of future injury. Future research should describe these measurement variables in greater detail to ensure consistent testing of ROM as a potential risk factor.

Contrary to the hypothesis, ankle dorsiflexion was also not found to have an association with injury in this review. Ankle sprains are highly prevalent in soccer players, and dorsiflexion limitations have been shown to decrease dynamic neuromuscular control in healthy adults (42) and strongly predict future ankle injuries in Army recruits.(4) A possible explanation for these contradictory findings is the variability in measurement of ankle dorsiflexion. Bradley et al(23) and Fousekis et al (29) utilized an open chain dorsiflexion measurement, using video analysis and goniometric measurements, respectively, while Engebretsen et al(25) describes ankle dorsiflexion measurement in limited detail. Conversely, Henry et al(31) utilized the WBLT, which is a closed chain measurement of ankle dorsiflexion. In a large study by Teyhen et al (5), asymmetrical ankle dorsiflexion was predictive of injury among warrior athletes. A difference of ≥6.5 degrees in ankle dorsiflexion, measured in a closed chain position, led to an OR of 4.10 (95% CI 1.40-11.70).(5) Studies included in this review utilized total dorsiflexion ROM but did not account for asymmetrical results. Clinically, closed chain dorsiflexion measurements may be the preferred measurement for soccer players as this more closely mimics how the joint is used in sport. Recent research indicates that perhaps asymmetry rather than total motion should be assessed for future injury risk determination.

The HQR has become a popular measure of strength, with lower eccentric hamstring strength having been thought to contribute to risk for ACL tear. Given the high prevalence of ACL tears in soccer players, particularly females, concern for this ratio is warranted. Though van Dyk et al determined that eccentric strength in both the quadriceps and hamstrings was predictive of injury, the authors concluded that the relationship was "weak" and other factors may need to be considered.(36) Using a clinic based measurement, Engebretson et al (26) found weakness of the adductors was predictive of future injury. Though adductor strength was assessed using a HHD, a definition for "weak" or cutoff value was not reported and was only described as "determined clinically." Overall, isokinetic measurements of strength may offer injury prediction information, however the relatively weak association to future injury may deter rehabilitation professionals from using an isokinetic machine clinically. Strength likely has value in injury prediction, however future studies should clearly define cutoffs and investigate a means of assessing strength that yields greater predictive value.

Neuromuscular control was only found to be predictive of injury in two studies.(30, 31) Measurement of neuromuscular control was different between nearly all studies included in this review. Henry et al (31) and Fousekis et al (29) used electronic devices to quantify neuromuscular control and proprioception, respectively, while Engebretsen et al (25), Nilstad et al (33) and Gonell et al (30) used field-based exams. Engbretsen et al (25) scored neuromuscular control on a five point scale while the subject performed single leg balance with eyes open and closed. Nilstad et al and Gonell et al utilized the SEBT with mixed results. This is a surprising finding, as low composite score on the SEBT has been found to be predictive of injuries in American football players (43), collegiate athletes (including soccer players)(17), and high school basketball players.(8) Asymmetry, particularly in the anterior direction, has also been predictive of future injury (8, 44), and Gonell et al (30) noted asymmetry in the posteromedial direction was a strong predictor of future injury. Though poor neuromuscular control has been traditionally considered a risk factor for future injury, more research is needed to determine its role in injury risk for soccer players.

Finally, additional functional measures found mixed associations with injuries. Only one study showed an association between 40m sprint times and injury in this population, however this was part of sub-analysis and scores were not reported.(26) A recent retrospective study in an active population revealed that slower run times on a 300m sprint were associated with injury (OR=1.47, 95% CI 1.16-1.85).(45) This same study also measured 1.5 mile run time and determined those with the slowest run times had a greater OR of 2.01 (95% CI 1.58-2.54). Slower time on distance runs (≥1 mile or greater) has been predictive of injury in other studies of warrior athletes as well.(46, 47)

These data suggest the fatiguing effects of longer distance runs may be more effective at identifying those at risk for injury. Additionally, only the single leg countermovement jump showed an association to injury in this review. Limited evidence exists regarding the predictive validity of the countermovement jump, however participation in an injury prevention program has been shown to improve countermovement jump height in youth soccer players.(48) Additional research is needed to explore this relationship and determine the validity of the countermovement jump in injury prediction. Finally the vertical drop jump did not show an association between greater knee valgus angles and increased risk for LE injury, though it did find a protective effect for ankle injuries. A recent review of vertical drop jumps revealed mixed results; the Landing Error Scoring System (LESS) may have potential, though conflicting results are present in the research.(49) Quality scores of the studies including additional functional measures ranged from 15-18. Overall, more research needs to be done to determine the role of these measures for injury prevention purposes.

Additional Risk Factors

Interestingly, trunk or core neuromuscular control deficit was not present in prospective studies regarding musculoskeletal injury risk for soccer players in the last 10 years. However, its relationship is present in previous studies of other athletic populations. A 2007 prospective study reported that greater trunk displacement after a sudden force release predicted future knee injuries in college-aged athletes (11). Subjects were required to sit in a semi-recumbent seat that controlled pelvic and LE motion, and trunk displacement was measured with an electromagnetic sensor. Lateral trunk displacement was the strongest predictor of future injury, with ORs of 2.14, 2.22, and 2.32 for knee, ligament, and ACL injuries, respectively. Finally, a recent prospective study found that those with a lower core neuromuscular control endurance measure predicted future core and LE strains and sprains in college football players.(12) Subjects were asked to hold a trunk flexion, back extension, and side bridge position to failure, and the time of each hold was measured in seconds. Though back extension and side bridge holds were not found to predict injury, a trunk flexion hold time of ≤161 seconds had an OR of 4.17 (95%CI=1.52-11.45).(12) While the evidence suggests utility of core neuromuscular control measures in LE injury prediction, the differing methods of measuring core neuromuscular control present a challenge for clinicians. In the future, it may be beneficial to utilize a more dynamic measure of core neuromuscular control to reflect the nature of soccer and its requirements for core neuromuscular control.

Though trunk or core neuromuscular control has been investigated as a risk factor for LE injuries, limited attention has been paid to trunk mobility, specifically axial rotation. To date, no study has examined the relationship between trunk axial rotation and LE injury, however the influence of trunk rotation on the overall efficiency of walking has long been documented biomechanically. (50) Though overlooked in the literature, trunk axial rotation could be an important variable to assess in soccer players. Thoracolumbar counter-rotation, combined with ipsilateral hip extension, is a strategy used to increase kicking power through production of a tension arc in the LE (51). Recently the role of trunk kinematics in soccer players was examined during a kicking maneuver. Using a three dimensional motion analysis system, Fullenkamp et al found that division I soccer players used 40° (±10°) of trunk rotation during a maximal instep kick (52). Additionally, a moderate positive correlation was found between peak trunk rotation velocity and poststrike ball velocity in this population (52). Though much of the literature has focused on LE kinematics during kicking, the authors conclude that trunk kinematics are “strongly tied to poststrike ball velocity” and should therefore be considered when developing training programs for soccer athletes (52). These findings are supported by Shan and Westerhoff, who conclude that effective upper body movement is related to more powerful kicks (53). It should be noted that trunk axial rotation was not measured segmentally in these studies; therefore, the individual contribution of lumbar and thoracic spines is unknown. Given the biomechanical differences between the lumbar and thoracic vertebrae, it is likely that the greatest contributor to trunk axial rotation would be the thoracic spine. Therefore limitations in thoracic spine rotation may impact LE kicking strategies and contribute to LE injury risk.

Gender and Level of Play

Though the samples within each study were similar, there was little homogeneity between studies in regards to gender and level of play. Only three studies included in this review researched specifically female soccer players, two of which had subjects under the age of 18 (Steffen et al and Clausen et al) while the remaining study followed elite players (Nilstad et al). All studies regarding females found previous injury to be a risk factor for future injury, and two identified the KOOS as being able to predict future injury as well (Steffen et al and Clausen et al). Nine studies specifically followed male soccer players, making applicability of these findings to females limited. It should be noted that four of the male-only studies were by Engebretsen et al, which utilized the same sample and data set. In male players, previous injury was found to predict future injury in four studies; three of these studies were by Engebretsen et al, though each was specific to include a respective joint or muscle (example: previous ankle injury predicts future injury). Three studies also found muscle strength was predictive of injury in male players, with hip adductor weakness predicting groin injuries (Engebretsen et al, 21) and eccentric hamstring strength predicting future LE injury (Van Dyk et al and Fousekis et al). The results of this review would suggest previous injury and muscle strength testing may be more effective at predicting LE injuries in males, while previous injury and the KOOS may be an option for injury prediction in females.

The majority of subjects in the included studies were amateur players, which is expected given that the number of professional players worldwide is small. Seven studies followed amateur players only. Previous injury was predictive of future injury in four studies of amateur players, and a low score on the KOOS was predictive of injury in three studies. Two studies found a relationship between neuromuscular control and future LE injury, though one (Gonell et al) included both amateur and professional players. Only four studies followed professional players, and two each found previous injury and eccentric hamstring strength to be predictive of future LE injury. Previous research in soccer players has indicated that level of play impacts injury risk. Van Beijsterveldt et al found that knee injuries were most common in professionals and ankle injuries were the most common in amateurs.(54) Severe injuries and recurrent injuries were more common in amateur players, despite the fact that professional team players have 2.70 times more training hours per player than their amateur counterparts.(54) Because there was so little consistency in measurement and assessment of risk factors in the included studies, it is difficult to determine the impact level of play has on injury risk factors. More research is needed in both the amateur and professional populations to draw conclusions regarding the impact level of play has, if any, on risk factors for LE injury in soccer players.

Given the disparity in studies including female subjects, at either level of play, caution must be used in interpreting these results. Female gender has been considered a risk factor for LE injury independently. This is especially true for ACL tears, where injury rates for females athletes are 3 times greater than their male counterparts.(55) Additional research has indicated that females will have different risk factors for LE injury than males, such as phase of menstrual cycle and generalized joint laxity.(56) It should be noted that these risk factors are intrinsic and therefore non-modifiable by rehabilitation professionals. While there is evidence to suggest that intrinsic, non-modifiable risk factors may differ by gender, more research is needed to determine the effects of gender on modifiable risk factors for greater clinical application.

Injury definition

Historically injury definitions have varied widely, making comparisons and interpretations of the literature particularly challenging. This is especially true when an athlete experiences a musculoskeletal injury, but does not withdraw from competition. Extensive and complex definitions have been used in the past in an effort to increase specificity of injury definition, however some level of subjectivity remained. In recent years, “time-loss” injury, or that which results in missing a scheduled practice, competition, or other training, has become the most popular definition. Though some studies specified “non-contact” mechanisms (Fousekis et al and Henry et al), it is worth noting that the injury definition of all studies included in this review had a time-loss requirement. This time-loss injury definition decreases subjectivity, increases continuity in the research, and allows for easier comparison and application.

Modifiability

Though many musculoskeletal injury risk factors exist for soccer players, it should be emphasized that all factors noted within this review have been found to be modifiable using common rehabilitation techniques. Exercise is the most common intervention prescribed by rehabilitation professionals. The most popular and relevant exercise program for soccer players is FIFA 11+. FIFA 11+ is a warm up program which consists of core stabilization, neuromuscular control training, eccentric strengthening, agilities and plyometrics. It also emphasizes running and jumping mechanics, particularly avoidance of knee valgus. A recent review of FIFA 11+ suggests that injury rates have been reduced by as much as 70% with regular performance of the program.(15) A recent meta-analysis of the FIFA Medical and Research Center (F-MARC) injury prevention programs determined that LE injury rates were reduced by 24% per 1000 hours of exposure.(57) High adherence to the program has also been found to further reduce injury rates.(15) With an approximate time investment of 15 minutes, 1-2 times per week, performance of FIFA 11+ has been shown to address neuromuscular deficits thus reducing overall injury rates.

Soft tissue and joint mobility restrictions can be addressed using common rehabilitation techniques as well. Manual therapy, including manipulation, mobilizations, and Mulligan mobilization with movement have all been shown to improve joint mobility measures.(58, 59) Instrument assisted soft tissue mobilization (IASTM) techniques may also be beneficial to improve hip mobility. In a recent randomized trial in soccer players, hamstring and quadriceps mobility was significantly improved immediately and 24 hours following IASTM treatment.(60) Finally, self-soft tissue mobilization, such as foam rolling, has also been shown to improve joint mobility measures.(61, 62)

Taken collectively, many exercises and manual therapy techniques exist to address the modifiable risk factors identified in this review. As Read suggests, modifiable neuromuscular risk factors should be paired with effective rehabilitation interventions(21) such as those discussed here to have the greatest impact on injury rates.

Conclusion

Several potential factors identifying soccer players at risk for future LE injuries have been identified in the literature. The results of this review indicate that previous history of injury is still the strongest predictor of future injury. Strength, neuromuscular control, ROM, and self-reported function may offer valuable information, but more research is needed to determine if these are valid predictors of future injury across genders and level of play in soccer players. Combining these factors in a single screening program may be beneficial to clinicians to comprehensively assess risk for all LE injuries, however it should be noted that the measurement of these factors varies widely across studies. Future research should describe the measurements in greater detail to improve continuity and reproducibility.

Chapter 3: Methods

There is a critical need for a comprehensive, systematic process of determining the presence of risk factors for LE musculoskeletal injury in soccer players utilizing reliable measurements with established predictive validity. Applying the results from the literature review, the following risk factors were chosen in order to have the broadest impact on LE injury prevention: pain with movement, mobility deficits (hip ER, ankle dorsiflexion, thoracic spine rotation), asymmetry in fundamental movement patterns (active straight leg raise, hurdle stepping, and in-line lunge), and neuromuscular deficits (Upper Quarter Y-Balance Test [YBT-UQ] and YBT-LQ). The measurements associated with all risk factors have established reliability in the literature, ranging from moderate to excellent (see Table 3.1, continued). Dichotomous cut-points, based on normative findings in soccer players or analogous populations, were created to determine presence or absence of risk factors. Finally, these risk factors were matched with common rehabilitation techniques to have the greatest impact on injury risk factor reduction.

Subjects

Returning men's and women's division I soccer players at a local university were recruited for this study. Study volunteers were issued and signed an informed consent. Informed consent and all study procedures were approved by the Institutional Review Board of the University of Kentucky in Lexington, Kentucky.

Table 3.1. Risk factor measurements and reliability.

Risk Factors	Test	Continuous Measurement	Reliability	Other Metrics	Dichotomous Pass	Dichotomous Fail
T-spine mobility	Lumbar locked thoracic rotation	Bubble goniometer: T-spine rotation	Intratester: ICC=.86-.90(63) Intertester: ICC=.87(63)	SEM: 2.00°-5.23° MDC: 5.53°-6.25°(63)	≥50°	<50°
Ankle mobility	Closed Kinetic Chain Dorsiflexion	Goniometer: Ankle dorsiflexion	Intraclinician: ICC=.88(64) Interclinician: ICC=.91(64)	SEM: 0.28-.41 MDC: 4.52°-4.66°(64)	Asymmetry of <5° or no asymmetry	Asymmetry of ≥5°
Ankle mobility	Closed Kinetic Chain Dorsiflexion	Goniometer: Ankle dorsiflexion	Intraclinician: ICC=.88(64) Interclinician: ICC=.91(64)	SEM: 0.28-.41 MDC: 4.52°-4.66°(64)	≥35°	<35°
Hip mobility	Prone passive ER	Goniometer: Hip ER	Intraobserver: ICC=.88(65) Interobserver: ICC=.66(65)	SEM: 3.0-5.0° (14) MDC: 8.3-13.8° (14)	≥40°	<40°
Fundamental movement	Supine active straight leg raise	Goniometer: Hip flexion	Intrarater: k_w=.60(66) Interrater: k_w=.69(66)	SEM: 0.92-0.98 MDC: 2.07-2.54(66)	Lateral malleolus of leg raised clears superior patella of contralateral leg	Lateral malleolus of leg raised does not clear superior patella of contralateral leg
Fundamental movement	Standing lunge	YBT-LQ; reach distances in cm or composite	Intrarater: k_w=.69(66) Interrater: k_w=.45(66)	SEM: 0.92-0.98 MDC: 2.07-2.54(66)	Able to complete a lunge pattern with feet 1 tibia length apart in tandem	Unable to complete lunge pattern with feet 1 tibia length apart in tandem

Fundamental movement	Standing hurdle step	YBT-LQ; reach distances in cm or composite	Intrarater: k_w=.59(66) Interrater: k_w=.67(66)	SEM: 0.92-0.98 MDC: 2.07-2.54(66)	Able to clear hurdle 1 tibia length from the floor, tap heel on the floor, then return to start position	Unable to clear hurdle 1 tibia length from the floor, tap heel on the floor, then return to start position
Core function	YBT-UQ	YBT-UQ; reach distances in cm or composite	Interrater: ICC=1.00(67)	SEM: 2.2-2.9 cm MDD: 6.1-8.1 cm(67)	Men: ≥85.1%, Women: ≥83.9%	Men: <85.1%, Women: <83.9%
Neuromuscular Control	YBT-LQ	Anterior reach distance in cm	Intrarater: .82(68) Interrater: .84-.88(69)	SEM: 0.69-0.71(68) MDC: 1.91-1.97(68)	Anterior reach asymmetry of <4	Anterior reach asymmetry of ≥4 cm
Neuromuscular Control	YBT-LQ	Reach distances in cm or composite	Intrarater: .82-.87(68) Interrater: .86-.91(69)	SEM: 2.08-3.31(68) MDC: 5.77-9.17(68)	>95%	≤95%
# of painful patterns	Pain with movement testing	Frequency count	---	---	No pain reported	Pain reported

Abbreviations: Thoracic spine (t-spine); Intraclass Correlation Coefficient (ICC); Standard Error of the Measurement (SEM); Minimal Detectable Change (MDC); External rotation (ER); Weighted kappa (k_w); Lower Quarter Y Balance Test (YBT-LQ); Upper Quarter Y Balance Test (YBT-UQ); Centimeters (cm); Minimal Detectable Difference (MDD).

Procedures

Informed consent was obtained from all 34 current players. Players completed a demographic form, which included gender and player position, as well as medical, surgical, and injury history information (Appendix C). Height and weight were measured using a standard beam scale with height rod. Subjects then performed a protocol of 6 warm up reaches in all directions on the YBT-LQ as described by Plisky et al to ensure maximal reach distances were achieved during testing.(8) Right upper extremity (UE) and right LE measurements were taken for individual normalization of the YBT-UQ and YBT-LQ, respectively. For right UE length, the subject was asked to abduct the arm to 90 degrees, and the examiner measured, to the nearest half centimeter, the distance from C7 spinous process to the tip of the longest finger. For right LE length, all subjects began in a hooklying position and were asked to perform a bridge. The examiner passively extended the legs after the bridge and measured, to the nearest half centimeter, the distance from the most distal aspect of the anterior superior iliac spine to the most distal aspect of the medial malleolus of the right LE.

With the exception of the fundamental movements, subjects did not wear shoes during collection of measurements. All procedures were performed bilaterally when applicable. Each procedure was repeated three times, with the best of the three trials being recorded for analysis. Reliability of all measurements is established in the literature and is summarized in Table 3.1. Images of testing procedures are available in Appendix B.

Subjects were measured for limitations in ROM in three areas: closed chain ankle dorsiflexion, hip ER, and lumbar locked thoracic rotation. Closed chain ankle dorsiflexion was measured in degrees using an inclinometer at the most distal aspect of the tibial tuberosity. The subject was positioned in half kneeling, with the leg to be tested forward and knee flexed to 90 degrees. While maintaining an upright trunk, the subject leaned forward, keeping the knee in line with the toes and heel in contact with the testing surface. A dorsiflexion measurement of <35 degrees, and/or an asymmetry of >5 degrees was considered a risk factor. Hip ER was measured in degrees using an inclinometer placed just superior to the lateral malleolus. The subject was positioned in prone, with the femur of the hip to be tested in neutral (i.e. parallel to the midline) and the knee flexed to 90 degrees. The rater measured maximal hip ER passively, while providing verbal and manual cuing to decrease pelvic or spinal compensations (such as loss of contact between the anterior superior iliac spine and the testing surface). Finally, thoracic spine rotation was measured in degrees with an inclinometer, with the subject in a lumbar locked position (full hip and knee flexion, full lumbar flexion). The subject's non-testing elbow was placed at his or her midline on the testing surface, with the dorsal aspect of the testing hand placed in the lumbosacral area. The inclinometer was centered at C7 interspace and the subject was asked to upwardly rotate toward the testing arm and ceiling. The rater providing verbal and tactile cuing to decrease lateral sidebending or other compensatory movement.

Neuromuscular control was assessed next using the YBT-LQ and YBT-UQ. For the YBT-LQ, subjects began with the right foot on the testing kit with toes behind the red line. Subjects pushed each slide box as far as possible with the left leg in the anterior direction while maintaining control (i.e. did not fall off kit or put foot down), with the best of three trials recorded to the nearest half centimeter. This procedure was repeated for all remaining directions bilaterally following the standard YBT-LQ protocol. For the YBT-UQ, subjects were in a push up position on the testing kit, with the thumb of the right hand aligned next to the red line. The subject then pushed the slide box in the medial, inferolateral and superolateral directions, respectively, as far as possible. This procedure was performed three times on the right side, then repeated on the left side. The subject was allowed one practice reach in each direction on each hand. .

Finally, fundamental movement was measured using three functional tasks: active straight leg raise, hurdle step, and in-line lunge. Active straight leg raise was measured with the subject in supine using an inclinometer and dowel rod. The dowel rod was aligned perpendicular to the testing surface at the subjects' mid-patella of the non-testing leg, while the inclinometer was placed at the superior femur. If the lateral malleolus of the testing leg did not pass the dowel rod, this was considered a risk factor. Range of motion was documented from the inclinometer measurement. For the hurdle step, the height was determined by aligning the hurdle with the subjects' tibial tuberosity. Beginning with the feet together and toes touching the back side of the hurdle, the subject was asked to lift the testing leg up and over the hurdle and tap the heel on the front side of the hurdle, then return to the starting position without touching the hurdle. During the in-line lunge, the subject is in tandem stance with the heel of the forward (testing) leg positioned one tibial length (measured from the superior middle of the subjects' tibial tuberosity to the ground) away from the toes of the back leg. The subject held a dowel rod vertically along the spine, with hand contralateral to the testing leg in the cervical lordosis, and hand ipsilateral to testing leg in lumbar lordosis. The subject completed a lunge movement, then returned to starting position.

Raters

Measurements were broken up into stations during testing to improve overall flow and decrease wait time for subjects. Nine raters were used during the screening process, each assigned to a specific station. Height and weight was measured by a pre-PT student, and UE and LE length was measured by a second year PT student. All other measurements were collected by licensed physical therapists with a range of 1-15 years of experience. Those raters with the fewest years of experience were enrolled in a sports residency, and those raters with the most experience were board certified in either sports or orthopedics. Each rater was trained in data collection procedures for his or her assigned station with verbal instructions and demonstrations. Each rater then performed data collection procedures on 10 individuals in front of the primary investigator to ensure procedures were followed and results were interpreted accurately.

Groups

Subjects with three or more risk factors were in the intervention group, and were treated one-on-one by a physical therapist according to the algorithm in Figure 3.1 (continued) where risk factors are treated according to rank. All identified mobility deficits were treated first before addressing any deficits in fundamental patterns or neuromuscular control. Additionally, deficits within each category were treated according to rank, with a one taking priority over two, and two taking priority over three. Each deficit has an associated treatment "package" that includes manual therapy treatment and therapeutic exercises designed to reinforce manual treatment and improve neuromuscular control (see Figures 3.2-3.4, continued; descriptions and pictures of all interventions are included in Appendices D-F). All treatments provided during one-on-one sessions were documented in a treatment log (see Appendix G) and compliance with one-on-one sessions was defined a priori as attendance of ≥90% of scheduled sessions. Players were treated 1-2 times per week for five weeks, and were instructed in home exercises to be performed independently between sessions. Compliance with home exercises was documented in an exercise journal (see Appendix H).

Figure 3.1. Intervention algorithm by category and rank.

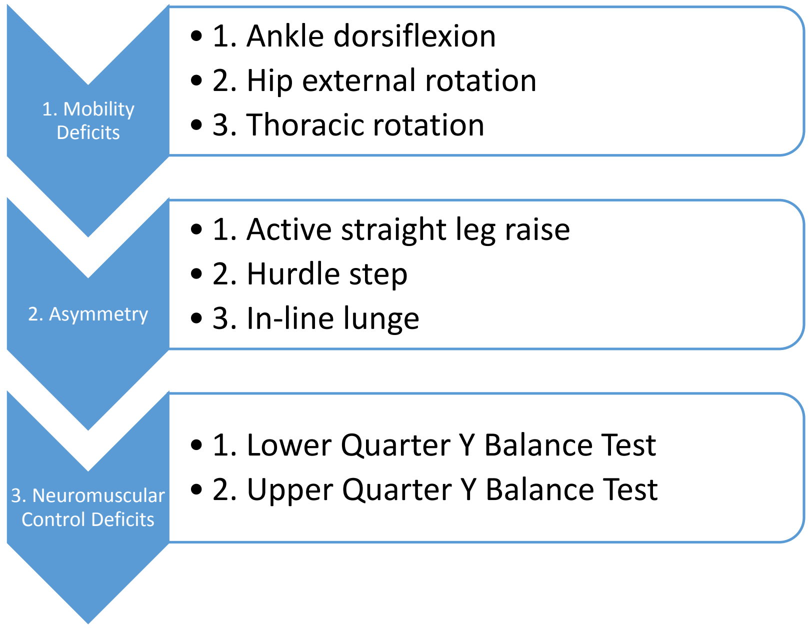
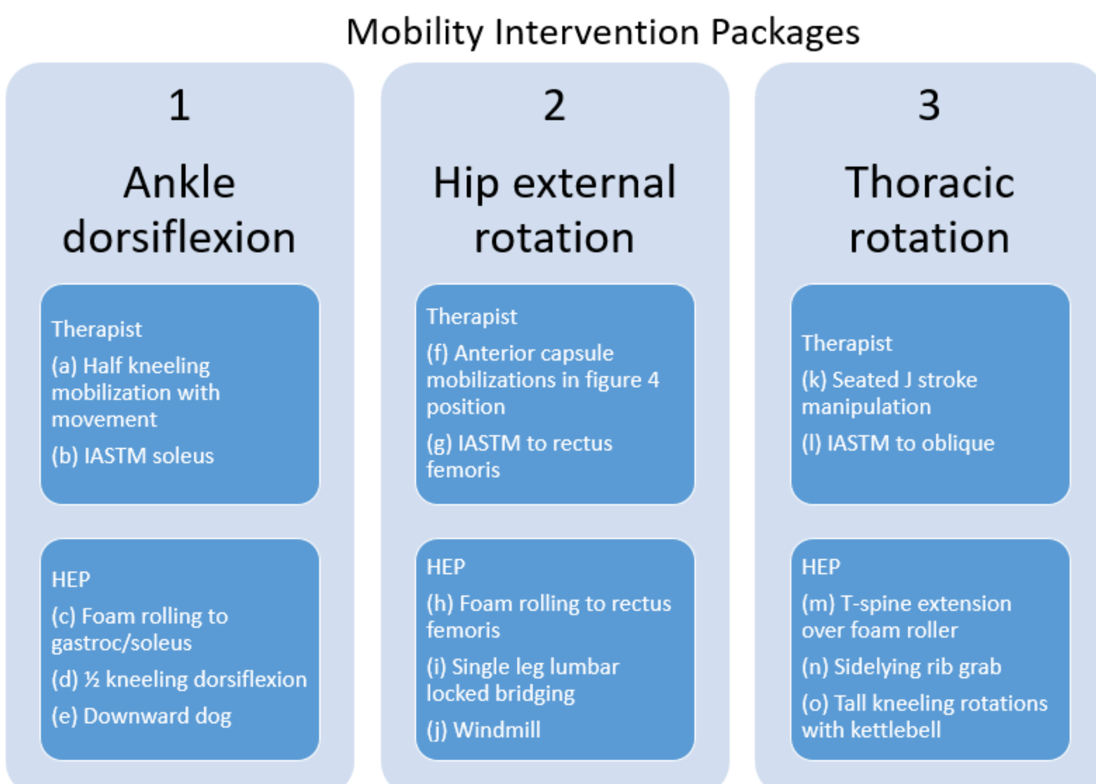
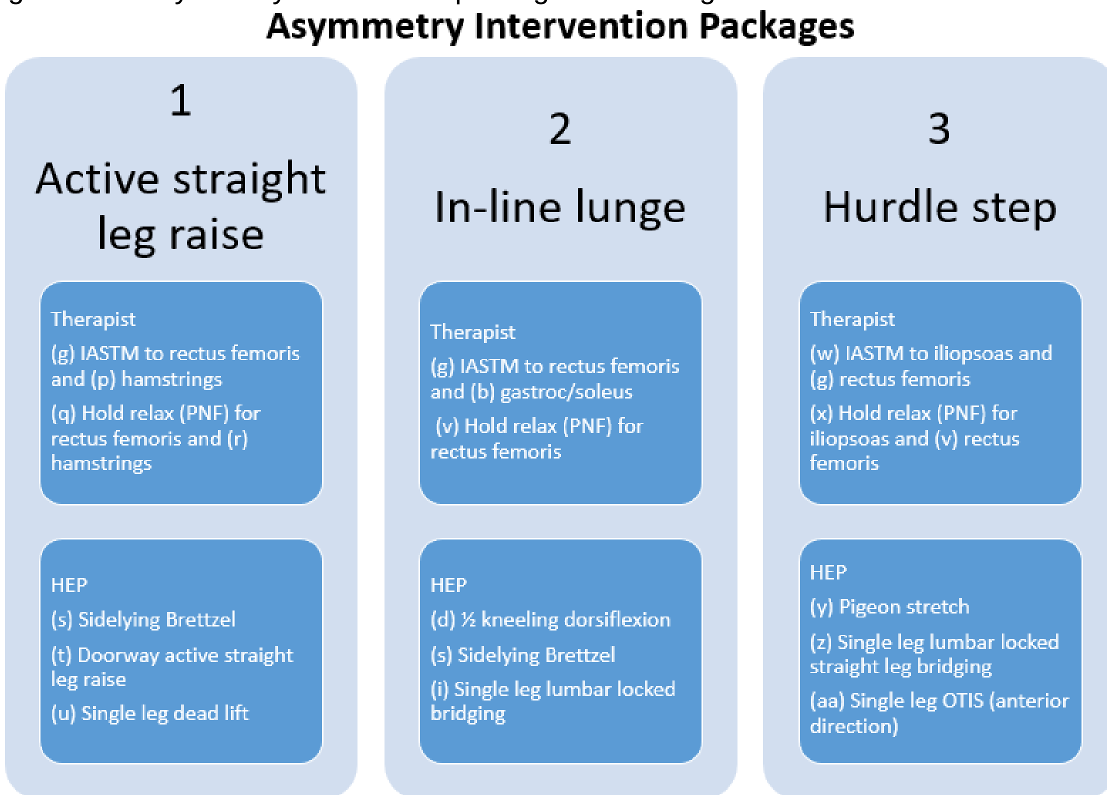


Figure 3.2. Mobility intervention packages according to rank



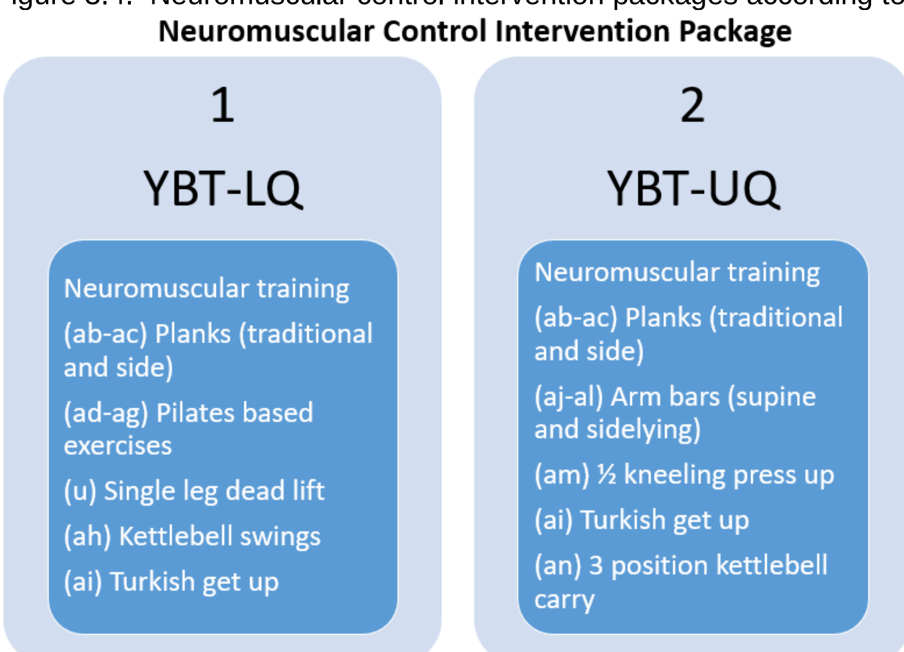
Abbreviations: IASTM=instrument assisted soft tissue mobilization. See Appendix D and corresponding letters for additional details.

Figure 3.3. Asymmetry intervention packages according to rank.



Abbreviations: IASTM=Instrument assisted soft tissue mobilization; PNF=proprioceptive neuromuscular facilitation; B=bilaterally; OTIS=oscillating technique for isometric stabilization. See Appendix E and corresponding letters for additional details.

Figure 3.4. Neuromuscular control intervention packages according to rank.



See Appendix F and corresponding letters for additional details.

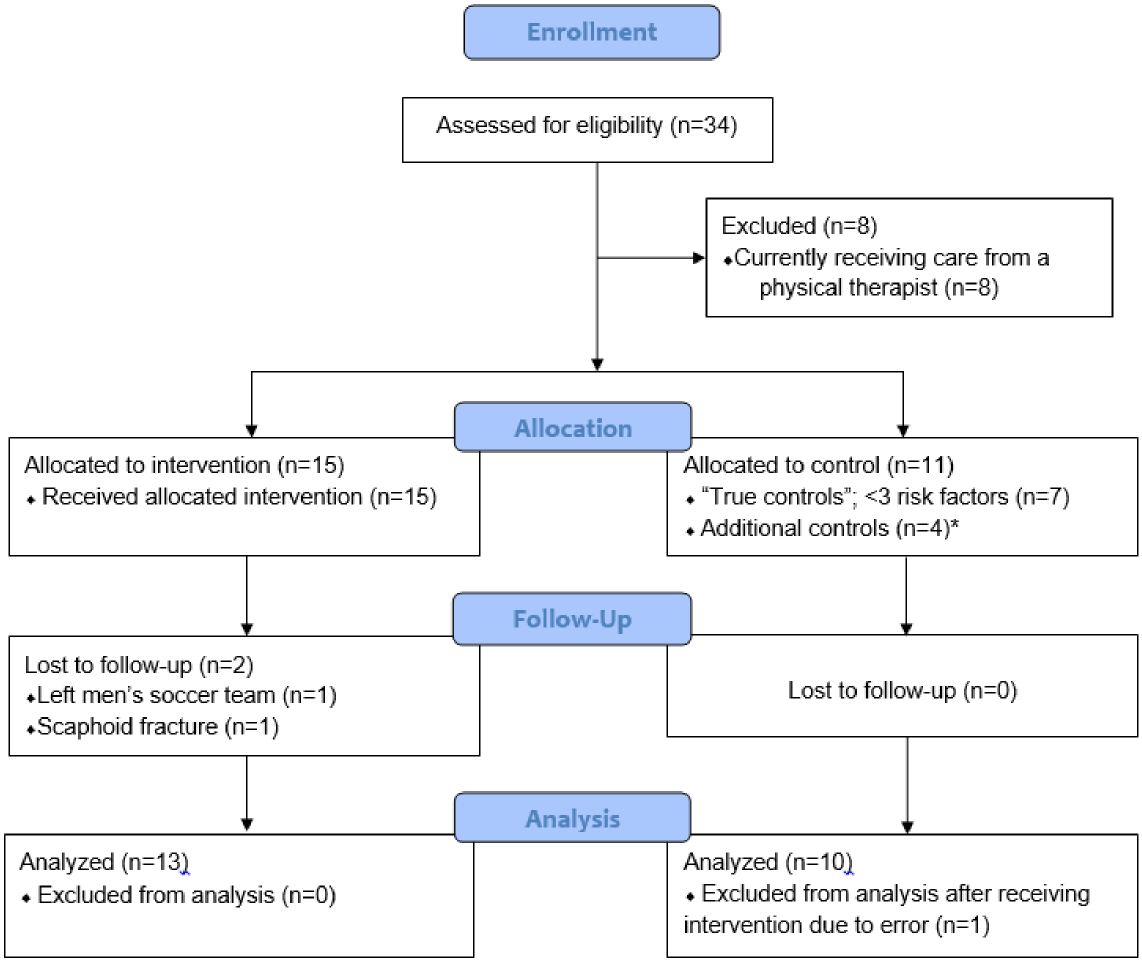
All treatments were provided by one of two physical therapists (PT's) based on the availability of subjects. Both PT's were assistant professors in a doctor of physical therapy program and have certifications in strength and conditioning (CSCS). Both have board certifications, one in sports and one in orthopedics, with eight and ten years of experience, respectively.

Subjects with <3 risk factors were placed in the control group and did not receive one-on-one intervention. Additionally, subjects that met the criteria to receive one-on-one intervention but declined treatment were also placed in the control group. The control group returned for posttesting only.

Chapter 4: Results

Fifteen subjects received one-on-one intervention. One subject in the intervention group sustained a scaphoid fracture after falling on an outstretched hand during a team scrimmage approximately two weeks after intervention began and was unable to participate in data collection at posttest. One additional subject in the intervention group left the men's soccer team after two weeks of intervention and declined to return for additional treatment or follow up testing. Seven subjects were "true controls", having <3 risk factors at pretest. Four additional subjects originally allocated to the intervention group declined one-on-one intervention and returned only for follow up testing. The data from these four subjects was combined with the "true controls" to form the control group utilized in the final analysis. Finally, one subject in the control group was treated two times due to error. This subject was excluded, leaving 10 subjects in the control group for final analysis (see Figure 4.1, continued).

Figure 4.1. CONSORT flow diagram.



*Subjects were originally allocated to the intervention group, but declined treatment and attended posttesting only. These subjects' data was combined with the "true controls" in the final analysis.

Demographic information for subjects in both groups is available in Table 4.1 (continued). There were no significant differences between groups at pretest. Though only one female was in the control group compared to five in the intervention group, the difference was not statistically significant (p=0.179). The frequency of risk factors present at pretest and posttest both for the intervention and control groups are summarized in Figures 4.2-4.4 (continued).

Table 4.1. Demographics.

	Intervention	**Control**	**p value†**
n	13	10	
Males	8	9	0.179
Height (inches)	70.58 ± 4.30	70.10 ± 2.44	0.741
Weight (pounds)	171.85 ± 20.36	169.80 ± 18.10	0.805
BMI	24.25 ± 2.24	24.25 ± 1.76	0.996
†p values were calculated using Fisher's exact test for gender, and 2 sample t-tests for all other variables.			

Primary Outcomes

The primary outcome was proportion of treatment successes in the intervention group, which was defined a priori as a reduction of ≥1 risk factors. Of the 13 subjects treated with one-on-one intervention, 12 had a reduction of at least one risk factor at posttest, therefore the proportion of treatment successes was 0.923 (95%CI 0.640-0.998). All 13 subjects in the intervention group had ≥3 risk factors at pretest ("high risk") and at posttest, 84.6% had <3 risk factors ("low risk"). A McNemar's test, a form of the Chi-square statistic where subjects act as their own control (70), was used to determine significant changes in risk category. The 2x2 contingency table for the intervention group is presented in Table 4.2 (continued). The number of subjects changing from a high risk category at pretest to a low risk category at posttest was statistically significant (p=0.003).

Table 4.2. 2x2 table for McNemar's analysis.

		Posttest		
		High Risk	Low Risk	*Total*
Pretest	High Risk (≥ 3 risk factors)	2	11	13
	Low Risk (<3 risk factors)	0	0	0
	Total	2	11	13

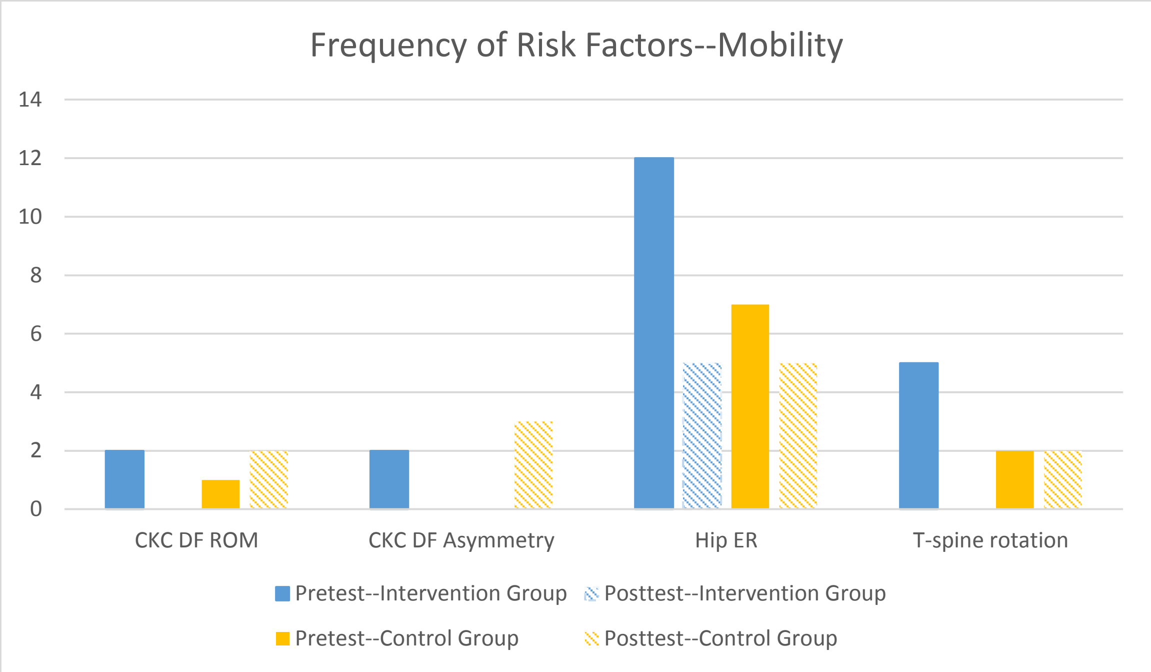
Of the 13 subjects treated with one-on-one intervention, only 10 were compliant (attending ≥90% of sessions). Of the 10 compliant subjects, 100% had a reduction of at least one risk factor at posttest. The proportion of treatment successes for compliant subjects was 1.00 (95%CI 0.69-1.00).

Secondary Analysis

A secondary analysis was performed on all continuous variables to determine within group and between group differences. Significant differences in continuous variables was not expected, as not all subjects possessed the same risk factors, therefore the study was not powered to capture these differences. However, capturing significant differences within and between groups could be of value. All continuous variables were analyzed for normality using a Shapiro-Wilk test. All variables were normally distributed except for number of painful patterns and total number of risk factors, because these were based on an ordinal scale. Secondary analysis of normally distributed continuous variables was performed using paired t-tests to determine within group differences, and independent t-tests to compare between group differences.

Mobility. Mobility deficits were the most common risk factors in both groups. In the intervention group, all subjects had at least one mobility risk factor at pretest with hip ER being the most common risk factor overall (n=12). In the control group, 80% of subjects had mobility deficits, with hip ER as the most common overall risk factor (n=7). Though no subjects in the control group had an asymmetry with closed kinetic chain dorsiflexion at pretest, this risk factor was present in three subjects at posttest. Finally, five subjects in the intervention group continued to have hip ER deficits while all other mobility risk factors were eliminated at posttest.

Figure 4.2. Frequency of mobility risk factors at pretest and posttest by group.



Abbreviations: Closed kinetic chain dorsiflexion (CKC DF); Range of motion (ROM); External rotation (ER); Thoracic spine (t-spine).

In the intervention group significant improvements were noted in right and left hip ER (p=0.000 and p=0.001, respectively), left active straight leg raise (p=0.017), and left thoracic rotation (p=0.026). No other significant changes in mobility were observed (see Table 4.3, continued). Finally, no significant differences in change scores were observed between groups (see Table 4.4, continued).

Table 4.3. Within group differences for mobility deficits in the intervention group as determined by paired t-tests.

Within Group Differences—Mobility				
Factor	Measurement	Mean	SD	p value
Closed Kinetic Chain Dorsiflexion (R)	Pre	38.30	5.50	0.051
	Post	40.90	3.07	
Closed Kinetic Chain Dorsiflexion (L)	Pre	40.80	6.20	0.317
	Post	42.00	3.13	
Active Straight Leg Raise (R)	Pre	80.10	7.36	0.343
	Post	81.60	7.86	
Active Straight Leg Raise (L)	Pre	77.1	8.52	0.017*
	Post	80.80	9.14	
Hip External Rotation (R)	Pre	32.50	8.71	0.000*
	Post	45.80	8.09	
Hip External Rotation (L)	Pre	35.4	8.18	0.001*
	Post	44.3	9.12	
Thoracic Spine Rotation (R)	Pre	57.70	14.56	0.161
	Post	64.00	7.07	
Thoracic Spine Rotation (L)	Pre	60.60	11.91	0.026*
	Post	67.60	7.18	

Abbreviations: Right (R); Left (L); Statistically significant (*).

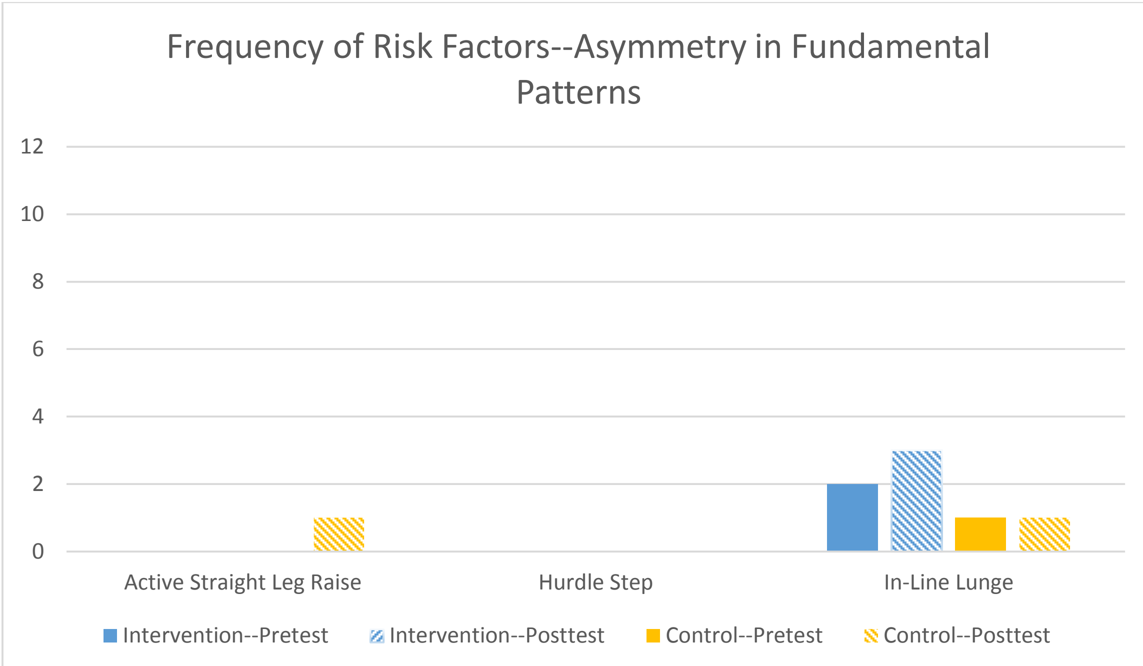
Table 4.4. Results of independent t-tests for mobility differences.

Between Group Differences—Mobility				
Factor	Group	Mean	SD	p value
Closed Kinetic Chain Dorsiflexion (R)	Control	1.30	1.49	0.598
	Intervention	1.92	3.43	
Closed Kinetic Chain Dorsiflexion (L)	Control	-.50	3.06	0.264
	Intervention	1.00	3.14	
Active Straight Leg Raise (R)	Control	-1.20	8.02	0.186
	Intervention	2.62	5.36	
Active Straight Leg Raise (L)	Control	.44	9.04	0.202
	Intervention	4.85	4.20	
Hip External Rotation (R)	Control	7.20	10.97	0.346
	Intervention	11.00	7.95	
Hip External Rotation (L)	Control	9.70	9.57	0.986
	Intervention	9.77	9.00	
Thoracic Spine Rotation (R)	Control	-.70	13.01	0.181
	Intervention	7.00	13.39	
Thoracic Spine Rotation (L)	Control	2.00	9.65	0.198
	Intervention	6.69	7.31	

Abbreviations: Standard deviation (SD); Right (R); Left (L).

Asymmetry in Fundamental Patterns. Fundamental pattern deficits were uncommon risk factors for both groups both at pretest and posttest. In-line lunge was the most common fundamental pattern deficit in both groups, though present in only three subjects total (Control=1, Intervention=2). The hurdle step was not a risk factor at pretest or posttest for either group. Both groups showed an increase in fundamental pattern deficits at posttest.

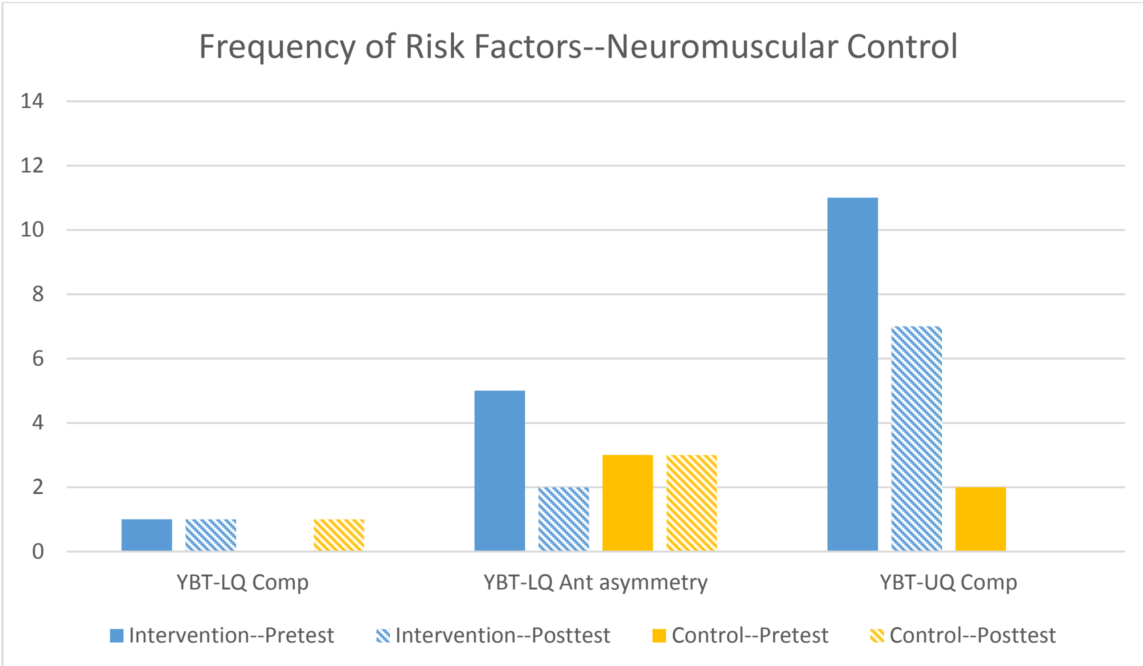
Figure 4.3. Frequency of asymmetry in fundamental pattern risk factors at pretest and posttest by group.



Few subjects in both groups had fundamental pattern risk factors at pretest and few changes were observed at posttest. Changes in dichotomous presence of risk factors (yes=present, no=absent) on the in-line lunge, hurdle step, and active straight leg raise from pretest to posttest were also analyzed using a McNemar's test. P values for all fundamental patterns for the intervention group, on right and left sides, were 1.00. Similarly, p values for fundamental patterns for the control group, on right and left sides, were 1.00 except for left in-line lunge, which was 0.480.

Neuromuscular Control. Anterior reach asymmetry on the YBT-LQ was the most common lower quarter neuromuscular control risk factor for the control group (n=3), though more prevalent in the intervention group (n=5). Anterior reach asymmetry persisted as the most common neuromuscular control risk factor for the control group at posttest (n=3).

Figure 4.4. Frequency of neuromuscular control risk factors at pretest and posttest by group.



Abbreviations: Lower quarter Y Balance Test (YBT-LQ); Anterior (Ant); Upper quarter Y Balance Test (YBT-UQ).

In the intervention group, no significant changes were noted in lower quarter neuromuscular control (see Table 4.5, continued). Additionally, no significant differences were observed between groups (see Table 4.6, continued).

Table 4.5. Within group differences in lower quarter neuromuscular control in the intervention group determined by paired t-tests.

Within Group Differences Neuromuscular Control—YBT-LQ				
Factor--Reach	Measure	Mean	SD	p value
Right Side				
Anterior	Pre	64.55	7.75	0.800
	Post	64.35	7.48	
Posteromedial	Pre	109.85	10.08	0.683
	Post	108.95	11.47	
Posterolateral	Pre	105.5	10.10	0.689
	Post	104.95	9.25	
Composite	Pre	102.82	6.09	0.823
	Post	103.10	8.28	
Left Side				
Anterior	Pre	66.05	7.87	0.220
	Post	64.5	6.56	
Posteromedial	Pre	107.85	17.02	0.508
	Post	110.70	10.30	
Posterolateral	Pre	105.30	11.16	0.312
	Post	103.90	9.62	
Composite	Pre	103.95	5.05	0.682
	Post	103.38	6.86	

Abbreviations: Lower quarter Y Balance Test (YBT-LQ); Standard deviation (SD).

Table 4.6. Results of independent t-tests for lower quarter neuromuscular control differences.

Between Group Differences Neuromuscular Control—YBT-LQ				
Factor--Reach	Group	Mean	SD	p value
Right Side				
Anterior	Control	-.85	5.99	0.986
	Intervention	-.88	2.97	
Posteromedial	Control	-.65	3.80	0.716
	Intervention	-1.46	6.09	
Posterolateral	Control	-2.15	7.71	0.530
	Intervention	-.58	3.93	
Composite	Control	-9.01	23.57	0.273
	Intervention	-.25	3.52	
Left Side				
Anterior	Control	-7.40	25.58	0.408
	Intervention	-1.38	3.33	
Posteromedial	Control	-13.75	38.69	0.299
	Intervention	-2.19	6.54	
Posterolateral	Control	-12.10	39.03	0.429
	Intervention	-1.85	3.86	
Composite	Control	-12.73	37.34	0.352
	Intervention	-1.10	3.88	

Abbreviations: Lower quarter Y Balance Test (YBT-LQ); Standard deviation (SD).

Upper quarter neuromuscular control deficits were the second most frequent risk factors in both groups. Eleven subjects in the intervention group had low composite scores on the YBT-UQ compared to only two in the control group. Low YBT-UQ composite score persisted as the most common neuromuscular control risk factor for the intervention group at posttest (n=7), though significant improvements were noted in the inferolateral reach (p=0.003) and composite scores (p=0.016) on the left at posttest (see Table 4.7, continued). No significant differences between groups were noted (see Table 11).

Table 4.7. Within group differences in upper quarter neuromuscular control in the intervention group determined by paired t-tests.

Within Group Differences Neuromuscular Control—YBT-UQ				
Factor--Reach	Group	Mean	SD	p value
Right Side				
Medial	Pre	82.40	7.29	0.121
	Post	87.75	5.15	
Superolateral	Pre	61.35	9.10	0.060
	Post	64.75	10.37	
Inferolateral	Pre	72.55	8.32	0.092
	Post	75.70	8.49	
Composite	Pre	81.78	6.21	0.178
	Post	83.96	8.73	
Left Side				
Medial	Pre	82.25	7.65	0.307
	Post	83.85	7.38	
Superolateral	Pre	62.80	9.96	0.128
	Post	65.3	10.50	
Inferolateral	Pre	71.95	8.54	0.003*
	Post	78.25	9.05	
Composite	Pre	82.05	6.44	0.016*
	Post	86.47	7.96	

Abbreviations: Upper quarter Y Balance Test (YBT-UQ); Standard deviation (SD).

Table 4.8. Results of independent t-tests for upper quarter neuromuscular control differences.

Between Group Differences Neuromuscular Control—YBT-UQ				
Factor--Reach	Group	Mean	SD	p value
Right Side				
Medial	Control	-2.25	9.80	0.959
	Intervention	-2.42	3.90	
Superolateral	Control	.50	9.14	0.485
	Intervention	2.69	5.60	
Inferolateral	Control	5.07	8.35	0.618
	Intervention	3.62	5.43	
Composite	Control	1.53	7.80	0.841
	Intervention	2.07	4.91	
Left Side				
Medial	Control	-.20	7.99	0.976
	Intervention	-.12	5.48	
Superolateral	Control	-.35	6.03	0.343
	Intervention	1.88	5.01	
Inferolateral	Control	3.10	9.97	0.458
	Intervention	5.73	4.88	
Composite	Control	1.16	6.98	0.376
	Intervention	3.44	5.12	

Abbreviations: Upper quarter Y Balance Test (YBT-UQ); Standard deviation (SD).

Because the number of painful patterns and total number of risk factors were not normally distributed, a Mann-Whitney U test was performed to determine differences between groups (see Table 4,9, continued). The median number of painful patterns (or tests) in both groups was zero, and changes from pretest to posttest between groups was not statistically significant (p=0.278). The median reduction of risk factors was -3 and -1 for the intervention and control groups, respectively. The difference in change in risk factors between groups was statistically significant (p=0.002).

Table 4.9. Results of Mann-Whitney U test.

Factor	Group	Median	Range	p value
Number of painful patterns	Control	0	-1, 5	0.278
	Intervention	0	-3, 3	
Total number of risk factors	Control	-1	-2, 4	*0.002**
	Intervention	-3	-5, 0	

Statistically significant (*).

Algorithm compliance. One physical therapist provided treatment for 93% of the one-on-one sessions. Minor modifications were made to the treatment algorithm based on several factors. Grades of joint mobilizations and intensity of soft tissue mobilization were adjusted based on subject comfort and tolerance. Verbal cuing during exercise performance varied from subject to subject based on observed deficits in performance. The most frequently modified intervention was the thoracic spine manipulation, which required the treating therapist to wrap his or her arms around the subject (see Appendix D for additional details). Due to a mismatch in size in some cases, an alternative position was used to perform the distraction manipulation. Length of treatment sessions also varied, ranging from 20-30 minutes, based on subject availability.

Chapter 5: Discussion

From our knowledge, this is the first study to use the total number of risk factors present to determine an individiual's risk for future LE musculoskeletal injury. The purpose of this study was to determine if one-on-one treatment—with interventions matched to address the specific deficits of each subject—was effective at reducing the number of risk factors for LE musculoskeletal injury. The interventions prescribed to each subject followed an algorithm consisting of soft tissue and joint mobilizations, followed by corrective exercises to improve fundamental movement patterns and neuromuscular control—all matched to the subjects' specific deficits. The results of this study indicate that one-on-one treatment with matched interventions is an effective approach to reducing the presence of risk factors in collegiate soccer players. This individualized approach to injury prevention programs has been successful in other athletic populations. Kiesel et al (2011) utilized individualized corrective exercises in professional football players to improve fundamental movement patterns. Movement deficits for each player were identified using the FMS. Prescribed exercises included self and partner soft tissue work and stretching, followed by exercises to improve core function and movement patterns. After seven weeks of intervention, a signficant number of subjects improved their FMS scores to ≥14 (X^2=164.90, P<0.01), a threshold that has been shown to decrease odds of future injury.(39) Additionally, a significant percentage of subjects eliminated movement asymmetries at posttest ($X^{2=}$7.80, P=0.01). Bodden et al utilized a similar individualized program in mixed martial arts athletes by combining self-mobility and corrective exercises, in an intervention group and compared to controls.(71) Significant changes in FMS score were noted in the intervention group after only 4 weeks of intervention ($X^{2=}$7.29, P<0.01), and significant differences between the intervention and control groups were noted at week 4 (F=15.51, p=0.001) and week 8 (F-14.40, p=0.001).(71) Taken collectively, programs targeting an individual's specific deficits with soft tissue and mobility interventions, followed by corrective exercises reinforcing fundamental movement patterns and neuromuscular control can be a successful approach to injury prevention.

Mean changes are often used to determine effectiveness of interventions. However, the effectiveness of the one-on-one, deficit-matched program could be lost if limited to this type of comparison. For example, in our study only two subjects in the intervention group had limitations in closed kinetic chain dorsiflexion ROM. Though both subjects experienced an increase in ROM (and an elimination of this risk factor), a significant difference in change scores was not observed because so few subjects had a dorsiflexion deficit. Therefore, examining effectiveness on an individual level may provide a more useful way of measuring success than comparing mean changes.

Risk Factors Changes

Mobility. All mobility risk factors were eliminated at posttest in subjects receiving one-on-one intervention except for hip ER deficits. Five subjects in the intervention group failed to eliminate limited hip ER as a risk factor at posttest. Three of these subjects improved hip ER between pretest and posttest measurements, with increases in ROM ranging from 6-15 degrees. Though substantial improvement was made in most cases, the posttest measurement still failed to clear the 40 degree threshold, leaving the risk factor ultimately unchanged. Given the progress observed, it is possible that this risk factor could have been removed with additional treatment sessions.

Other research has indicated that limitations in hip moblity may be due to dysfunction in adjacent areas. Cibulka et al found asymmetries in hip rotation in individuals with sacroiliac joint pain.(72) Additionally, pain in the lumbar spine may contribute to limitations in hip rotation in athletes participating in rotational sports.(73) Treatment to the lumbopelvic region was not included in the treatment algorithm, therefore subjects with dysfunction in these areas resulting in hip rotation limitations would not have seen improvement with one-on-one treatment.

Asymmetry in Fundamental Patterns. Very few subjects in either group were observed to have fundamental pattern limitations or asymmetries. Given that so many subjects had mobility limitations, it was expected that these limitations would impact performance of fundamental patterns. Dichotomous scoring of the patterns may have led to this unexpected result. Fundamental patterns were the only tests that did not have a corresponding continuous measure, thus decreasing sensitivity and precision of measuring change.

Fundmental pattern scoring was adapted from the FMS scoring (see Table 5.1, continued), where 0's and 1's were interpreted as a "yes" (risk factor present) and 2's and 3's were interpreted as a "no" (risk factor absent). Though reliability of the FMS has generally been good to excellent and many studies have shown a relationship to musculoskeletal injury with poor performance and/or asymmetry (39), it's ability to predict future injury has been debated in the literature. For example, in a population of athletes including soccer players, Warren et al found that a score of 0 or 1 on the active straight leg raise, hurdle step, and in-line lunge did not significantly increase the odds of a future non-contact injury, with ORs ranging from 0.34-0.63.(74) Additionally, no significant increase in ORs was observed in athletes with asymmetries on the active straight leg raise (OR=1.38, 95%CI 0.63-2.97), hurdle step (OR=1.29, 95%CI 0.53-3.11), or in-line lunge (OR=0.54, 95%CI 0.26-1.11).(74) Therefore, it is possible that fundamental pattern limitations or asymmetries may not impact future injury risk.

Table 5.1. Original Functional Movement Screen scoring and study-adapted scoring.

Original		Adapted
0	Pain noted when performing the movement	Yes (Present)
1	Unable to complete the pattern, or attain the start position for the pattern	
2	Completes the pattern with compensation	No (Absent)
3	Completes the pattern with no compensation	

Neuromuscular Control. All 11 subjects with upper quarter neuromuscular control deficits also had a least 1 mobility risk factor, most commonly limited hip ER (n=10). According to the algorithm, all mobility risk factors were to be eliminated before progressing to higher level neuromuscular control interventions. This is based on classic neurodevelopmental and motor control theories, where normal joint mobility is attained before static and dynamic neuromuscular control can develop normally.(75) Because all subjects began the intervention period receiving treatment for mobility deficits, less time was spent on higher level neuromuscular control exercises. In 95% of subjects where upper quarter neuromuscular control deficits were present, exercises to address these deficits were not introduced until week 2 or later of the intervention period. With comparatively less time spent learning to control newly acquired or recovered mobility, translation to improved neuromuscular control measures may have been limited.

Pain. Though no treatment was provided to address pain specifically, the algorithm followed a regional interdependence rationale where treatment provided to adjacent areas would improve local symptoms. Wainner et al describes regional interdependence as "the concept that seemingly unrelated impairments in a remote anatomical region may contribute to, or be associated with, the patient's primary complaint".(76) A subject with limited hip mobility and low back pain, for example, may see improvements in low back symptoms with interventions targeting hip mobility. In this study, no change in painful patterns was observed. This may have been due to the chronic, “sub-clinical” nature of a subject’s pain. Many subjects reported having symptoms, primarily back pain, for years though they had not received formal treatment from a physician or physical therapist in several months. Previous research has noted neurophysiologic changes, including hypoalgesia, with localized manual therapy in individuals with musculoskeletal pain.(77) Therefore, the subjects in this study may have required localized manual therapy treatment for pain relief to observe a change in painful patterns.

Analysis Modifications

It is possible that the results of this study overestimate risk factor reductions. The threshold for testing postive for any risk factor was operationally defined based on recent evidence regarding injury prediction. Initial analysis of data was performed as proposed a priori without consideration for minimal detectable difference (MDD). Minimal detectable difference (also known as minimal detectable change) is the amount of change in a variable that exceeds measurement error, and represents a true change.(70) It is calculated using the following formula:

$$MDD = SEM * Z * \sqrt{2}$$

where SEM is the standard error of the measure and Z is from the normal distribution, representing confidence. The MDD for each risk factor was calculated using a Z score of 1.96 to represent 95% confidence. All subjects receiving one-on-one intervention had a reduction in 1 or more risk factors after the intervention period. However in some cases, these reductions crossed the operationally defined risk factor threshold while failing to exceed the MDD of the accompanying continuous measurement. Failing to exceed the MDD means that the change observed may have been due to measurement error and may not represent a true reduction in a risk factor. For example, one female subject had low composite scores on the YBT-UQ on the right and left sides at pretest, with scores of 80.1 and 83.5, respectively. The cutoff for passing the YBT-UQ composite score (thereby removing this risk factor) for females was 83.9. At posttest, the right and left composite scores for this subject were 84.80 and 86.40, respectively. The MDD for the YBT-UQ composite score has been reported as 6.10-8.10.(67) Though the posttest scores crossed the threshold for this risk factor, because the change scores for this subject fell below the MDD, it is likely the change observed is due to measurement error and not a true change in the risk factor.

A modified analysis was performed requiring the observed change for each risk factor to cross the operationally defined threshold as well as exceed MDD to qualify as a risk factor change. Individual results for the intervention and control groups are summarized in Appendix I and J, respectively. Despite using a more conservative estimate, the Mann-Whitney U test revealed a statistically significant difference between the intervention and control groups with a p value of 0.003 (see Table 5.2, continued).

Table 5.2. Modified analysis Mann Whitney U results.

Factor	**Group**	**Median**	**Range**	**p value**
Total number of risk factors	Control	0	-2, 4	0.003*
	Intervention	-3	-5, 0	

Statistically significant (*).

Control Group Changes

Interestingly, subjects in the control group experienced changes in risk factors despite not receiving intervention. In the original analysis, subjects in the control group had a median reduction of risk factors of -1. However, the changes observed did not result in a meaningful reduction in injury risk in all subjects. Of the 5 subjects that eliminated ≥1 risk factors, only 3 subjects changed from “high risk” (≥3 risk factors) to “low risk” (<3 risk factors) at posttest. Conversely, 3 “high risk” control subjects also increased number of risk factors from pretest to postest. Because recent research suggests a linear relationship of number of risk factors present to injury risk, any increase in risk factors from pretest to posttest for the “high risk” controls translates to increased injury risk. Using the modified analysis, the median reduction was 0, though this did not impact risk category changes.

Subject Compliance

Three subjects received one-on-one treatment but were considered non-compliant due to poor attendance of treatment sessions. One subject attended only one treatment session and no change in risk factors was noted from pretest to posttest. The remaining non-compliant subjects attended three one-on-one sessions each, with reductions in risk factors of -1 and -5. These findings suggest that significant improvement may be possible in fewer treatments, though more than one treatment session is likely needed. Additionally, compliance with independent performance of prescribed home exercises is uncertain. Subjects in the intervention group were asked to perform prescribed exercises at least once daily and record performance in a journal supplied to them. Exercise journals were to be returned each week to record compliance and update prescribed exercises. Unfortunately only one subject returned an exercise journal and only one time during the intervention period, therefore compliance with independent performance of prescribed exercises cannot be estimated. Recent research has suggested that dosage of exercise interventions can impact efficacy and results (78), so careful consideration must be taken when selecting parameters for prescribed exercises. Though dosage of an intervention should be individualized for each subject and take into account length and intensity of the particular cycle of the sport season, knowledge of an approximate dosage of intervention would be beneficial for clinicians in planning and implementing an injury prevention intervention.

Clinical Implications

The interventions included in the algorithm were selected based on current evidence, as well as clinical expertise of the treating physical therapists. Though not the primary focus of this study, the interventions selected certainly play a role in the effectiveness of the algorithm. In all cases, it is possible that another manual technique or exercise would have yielded similiar improvement in outcome measures. For these results to be reproduced in a clinical setting, rehabilitation professionals should utilize interventions within their scope of practice and training. Pragmatically, of greatest importance is not that these specific interventions are followed, but that identified deficits are matched with interventions designed to improve them, and that impairments are immediately reassessed after the treatment to determine the effectiveness of the technique.

The timing of the intervention period coincided with the spring season, where volume and intensity of workouts, practices, and games are decreased. To date, no study has examined the effectiveness of an intevention program related to cycle of season (example: pre-season versus off-season). Group injury prevention programs have been successful at decreasing injury rates. A recent systematic review of the FIFA 11+ reports that these programs were performed 1-6 times per week, for 4-10 months during season play.(15) Effectiveness of the prevention program in this study may not solely be due to the one-on-one nature of interventions. Changes in risk factors may have occurred more readily in this study because athletic demands were lower during the spring season. Therefore, clinicians should utilize caution when selecting a time to implement an injury prevention program such as this one.

Limitations

As demonstrated by the literature review, there is limited consistency regarding which factors contribute to LE injury in soccer players. The purpose of this study was to combine risk factors common to multiple LE injuires to have a broader effect in injury reduction. The risk factors selected for the study have an association to LE injury in soccer players or other athletic populations, though the strength of evidence supporting each factor varies. For example, hip ER deficit was the most prevelant risk factor amongst both groups, with 82.6% of all subjects having at least one hip that failed to clear the 40 degree threshold. However, the strength of evidence supporting the ability of limited hip ER to predict LE injury is less robust than other factors. In 58.3% of cases, the interventions selected were successful at eliminating limited hip ER as a risk factor. Still, it is possible that elimination of this risk factor does not translate to a meaningful reduction in LE injury risk. Other studies have combined risk factors and stratified subjects using a weighted algorithm, where the most robust risk factors carry greater weight than less robust risk factors.(17) Weighting risk factors would allow resources to be allocated to those individuals that need it most and injury prevention efforts to be focused on areas that would produce meaningful reductions in injury risk.

Long term follow up was not feasible for this study, therefore maintenance of risk factor reduction and impact on future LE risk is unknown. Most of the subjects in this study were returning home for the summer to train or compete in local travel teams. Without continued performance of corrective exercises during training, it is possible that the risk factors would return and injury risk would increase. Additionally, it is unknown if removal of these risk factors translates to a decrease in injuries. It is recommended that future studies utlize a long term follow up, preferably following in-season play, to determine changes in number of risk factors over time as well as translations to injury rate reduction.

Conclusion

Utilizing one-on-one interventions designed to target evidence-based injury risk factors is an effective strategy to eliminate LE musculoskeletal injury risk factors. Future research should clearly describe measurement procedures for previously defined risk factors to allow for greater reproducibility and applicability in clinical settings.

Additionally, utilization of a long term follow up is necessary to determine if elimination of musculoskeletal risk factors translates to decreased injury risk.

Appendix A

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported
Objectives	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design	4	Present key elements of study design early in the paper
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	9	Describe any efforts to address potential sources of bias
Study size	10	Explain how the study size was arrived at
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) If applicable, explain how loss to follow-up was addressed
		(*e*) Describe any sensitivity analyses

Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
		(c) Summarise follow-up time (eg, average and total amount)
Outcome data	15*	Report numbers of outcome events or summary measures over time
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period

Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
Discussion		
Key results	18	Summarise key results with reference to study objectives
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability	21	Discuss the generalisability (external validity) of the study results
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

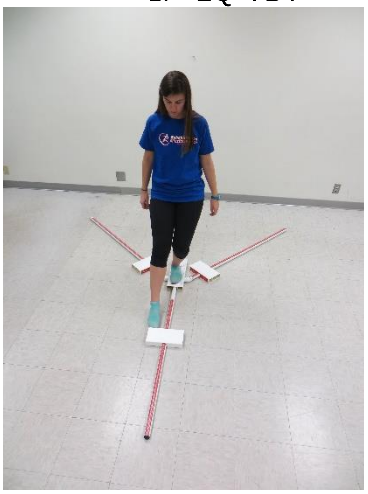
*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

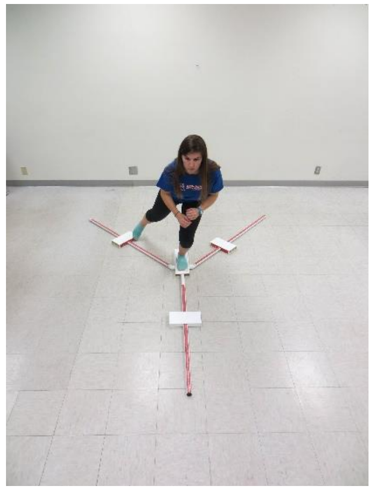
Appendix B

Data Collection Procedures

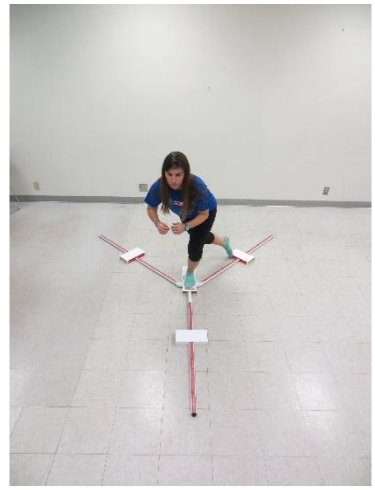
1. LQ-YBT



Anterior

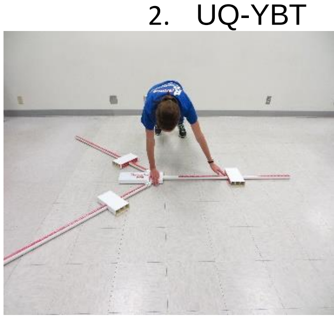


Posteromedial



Posterolateral

2. UQ-YBT



Medial

Superolateral

Inferolateral

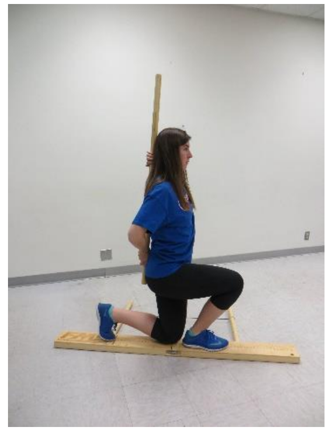
3. Hurdle Step

Tibial crest height

Start position

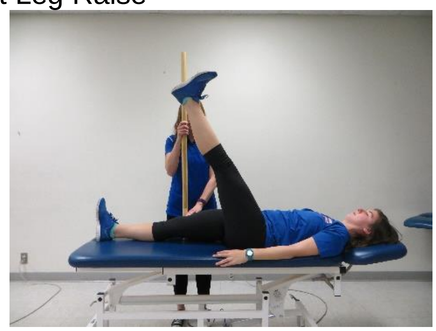
Hurdle stepping

4. Lunge

Start position Lunge

5. Active Straight Leg Raise

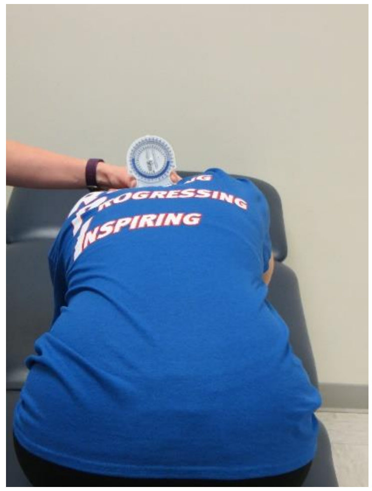


End range

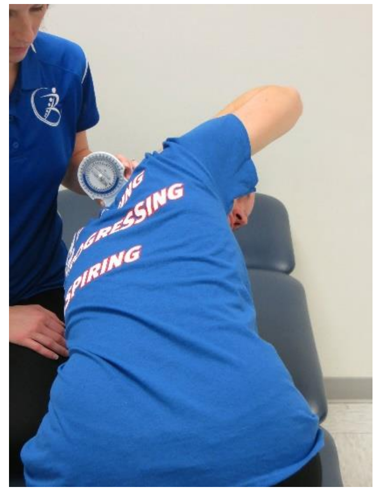
6. Prone active hip external rotation

End range

7. Lumbar locked thoracic rotation



Start position



End range

8. Closed kinetic chain dorsiflexion

Start position

End range

*If any athlete is unable to assume starting position, he or she will fail that portion of the screen.

Appendix C

University of Kentucky

Data Collection Form

Today's Date: ______________

First name:__________ Last Name:____________ Birth Date:_________

Sport:_______________ Position: ______________ Height:______

Weight: _____

Please answer the following questions:

1. Have you had a surgery in the last 3 months? Yes No

   If yes, please provide date of onset and type of surgery:_____________

2. Are you currently under practice or workout restrictions due to a musculoskeletal injury?

   If yes, please provide date of onset and type of injury: ________________

3. Are you currently under practice or workout restrictions for any other medical reason?

   If yes, please provide date of onset and reason: _________________________

Right LE limb length ____________cm (Distal ASIS to Distal Medial Malleolus)

Lower Quarter YBT (cm)		
Direction	**Right**	**Left**
Anterior		
Posteromedial		
Posterolateral		

Pain with testing: ____________________________

Right UE limb length ______cm (C7 spinous process to end of longest finger)

Upper Quarter YBT (cm)						
Direction	**Right T1**	**Right T2**	**Right T3**	**Left T1**	**Left T2**	**Left T3**
Medial						
Superolateral						
Inferolateral						

Pain with testing:_____________________________

Fundamental Pattern		Pass	Fail
Hurdle Step	Right		
	Left		
In-Line Lunge	Right		
	Left		
Active Straight Leg Raise	Right		
	Left		

Pain with testing:______________________

Active Range of Motion (degrees)		
Prone Hip External Rotation	Right	
	Left	
Lumbar Locked Thoracic Rotation	Right	
	Left	

Pain with testing:__________________________

Closed Kinetic Chain Dorsiflexion		
	Right	Left
Degrees		

Pain with testing:_____________________

Appendix D

MOBILITY INTERVENTIONS

Ankle Dorsiflexion

(a) Half kneeling mobilization with movement

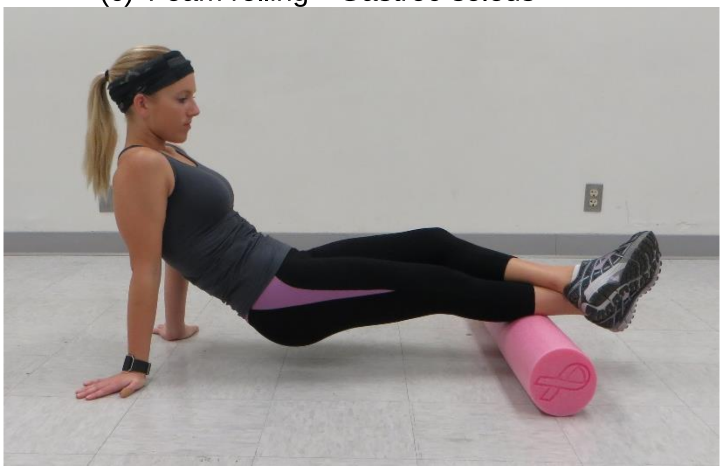
Details: The subject begins in half-kneeling, with knee and ankle flexed to 90 degrees, and ankle to be treated forward. The therapist provides a posterior force to the subject's talus as the subject shifts his or her weight forward with an upright trunk, advancing the tibia to produce closed kinetic chain dorsiflexion.

(b) Instrument Assisted Soft Tissue Mobilization (IASTM)—Soleus

Details: An instrument was used to mobilize soft tissue trigger points or painful areas in the soleus muscle.

Ankle Dorsiflexion Home Exercise Program (HEP)

(c) Foam rolling—Gastroc-soleus



Details: The subject places the leg to be treated on top of the foam roller, crossing the contralateral leg on top. Lifting the hips off the floor, the subject then rolls over the soft tissue of the gastroc-soleus complex to mobilize trigger points or painful areas.

(d) Half kneeling dorsiflexion

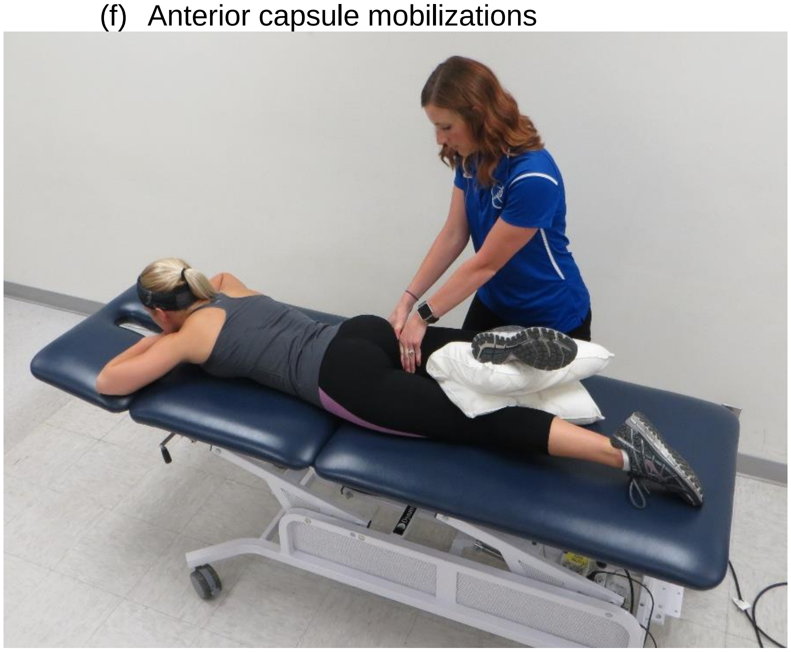
Details: The subject begins in a half kneeling position, with knee and ankle flexed to 90 degrees, and leg to be treated forward. The subject shifts his or her weight forward with an upright trunk, advancing the tibia over the toes to produce closed kinetic chain dorsiflexion.

(e) Downward dog

Details: The subject begins in a modified push up position, with hips raised toward the ceiling, bearing weight through hands and feet. The subject then pushes through the floor with his or her hands, keeping the knees extended, to produce a stretch in the gastrocnemius muscles.

Hip External Rotation

(f) Anterior capsule mobilizations



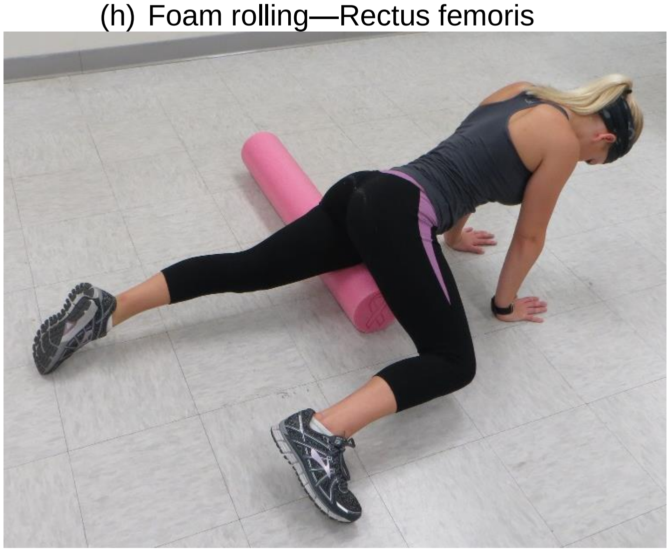
Details: The subject lies in prone with the hip to be treated slightly abducted and knee flexed. With the subject's foot supported by a pillow, the therapist applies an anterior glide to the posterior aspect of the femoral acetabular joint.

(g) IASTM to Rectus femoris

Details: The subject lies in supine while the therapist uses an instrument to mobilize trigger points or painful areas in the rectus femoris muscle.

Hip External Rotation HEP

(h) Foam rolling—Rectus femoris



Details: The subjects lies in prone with the leg to be treated in direct contact with the lateral edge of the foam roller, and the contralateral hip flexed and abducted off to the side. The subject then rolls over the tissue of the rectus femoris to mobilize trigger points or painful areas.

(i) Single leg lumbar locked bridging

Details. Start: The subject begins in hooklying position with the foot of the leg to be treated flat on the table and contralateral knee flexed up toward the chest. Finish: The subject holds the knee tightly toward the chest using his or her hands, while lifting the hips toward the ceiling by pushing through the heel.

(j) Windmill

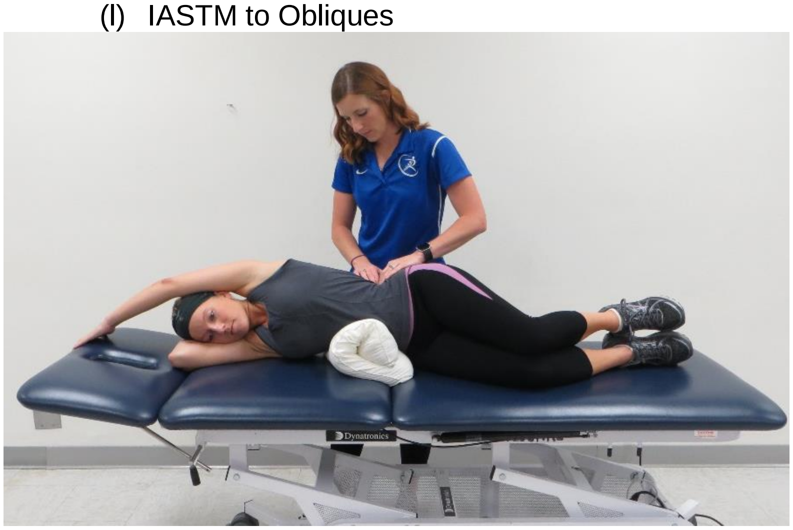
Details. Start: The subject starts in half kneeling, with hip to be treated forward and contralateral leg externally rotated so that the feet are perpendicular to each other. Finish: The subject shifts weight away from the forward leg, lowering contralateral hip toward contralateral heel until contralateral palm contacts the floor.

Thoracic Rotation

(k) Seated J stroke

Details: The subject is seated on the edge of a plinth with arms crossed over chest. The therapist wraps his or her arms around the subject, with hands clasped over the subject's elbows. The therapist applies a posterior and inferior force through the subject's elbows before providing a superior distraction thrust, using a "J" shaped maneuver.

(l) IASTM to Obliques



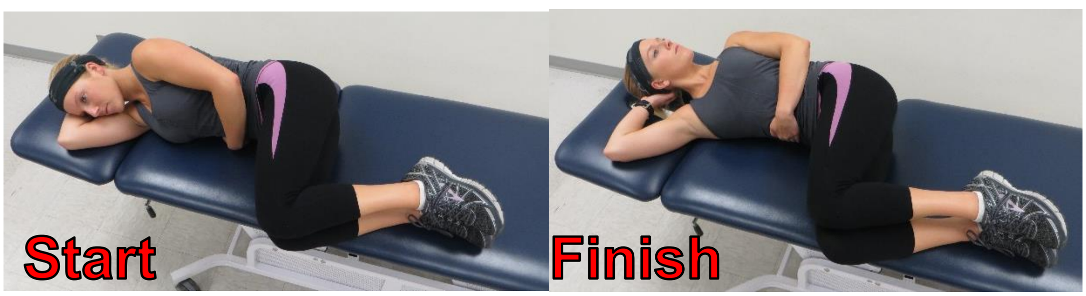
Details: The subject is positioned in sidelying, with side to be treated toward the ceiling. A pillow or bolster was placed between the contralateral lower ribs and iliac crest. The arm of the side to be treated is abducted overhead to increase tissue stretch while the therapist mobilizes trigger points or painful areas in the oblique muscles.

Thoracic Rotation—HEP

(m) T-spine extension over foam roller

Details: The subject begins in hooklying, with the foam roller positioned at the mid-thoracic spine. After lifting the hips, the subject rolls over the foam roller and performs extension segment by segment throughout the thoracic vertebrae.

(n) Sidelying rib grab



Details. Start: The subject starts in sidelying with the side to be treated toward the ceiling and ipsilateral hand draped over the stomach, grasping the contralateral ribs. Finish: The subject then rotates posteriorly, retracting the ipsilateral scapula toward the table.

(o) Tall kneeling rotations with kettlebell

Details. Start: The subject begins in tall kneeling, with knees abducted slightly wider than hips and heels of both feet touching. Finish: While holding the kettlebell directly behind him or her, the subject rotates towards one side, maintaining an upright trunk and retracted scapulas before rotating toward the opposite side.

Appendix E

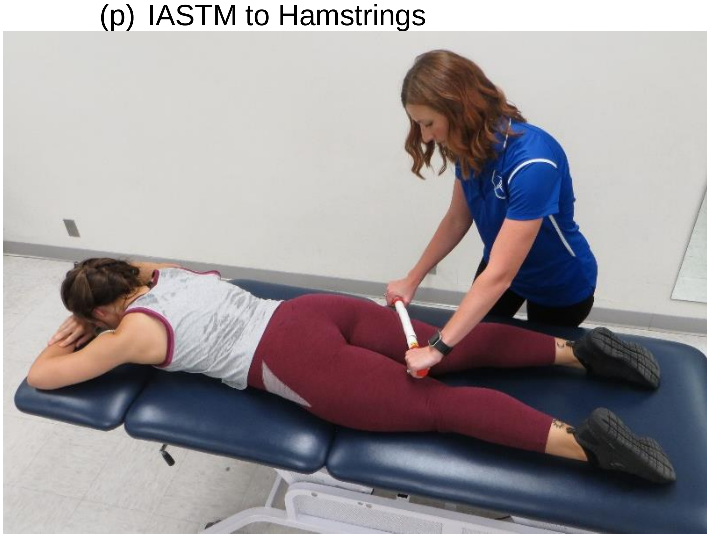
Asymmetry Interventions

Active Straight Leg Raise

(g) IASTM to Rectus femoris

Details: The subject lies in supine while the therapist uses an instrument to mobilize trigger points or painful areas in the rectus femoris muscle.

(p) IASTM to Hamstrings

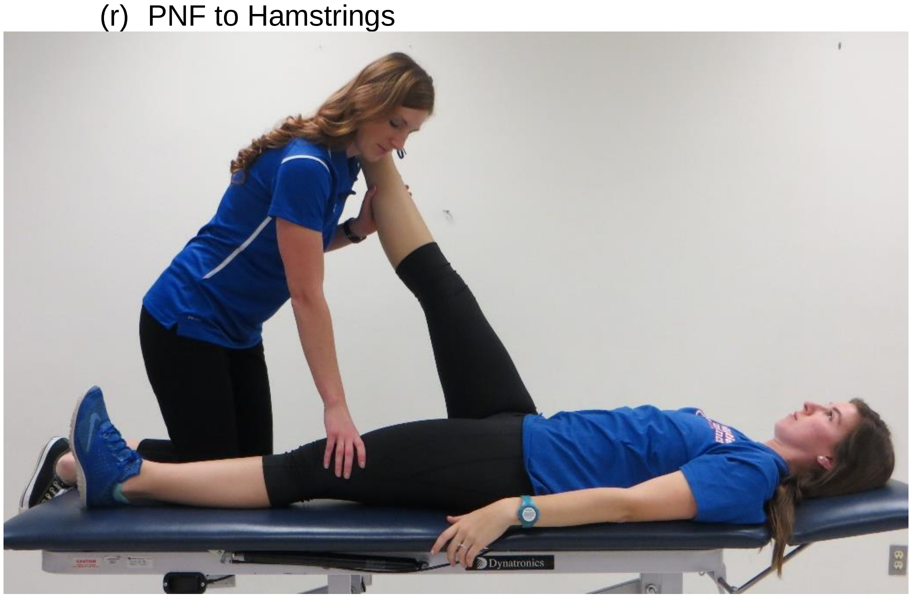


Details: The subject lies in prone while the therapist uses an instrument to mobilize trigger points or painful areas in the hamstring muscle group.

(q) Proprioceptive Neuromuscular Facilitation (PNF) to Rectus femoris

Details: The subject lies in a modified prone position, with the contralateral foot flat on the floor and the leg to be stretched on the table with the knee flexed to 90 degrees. The therapist stabilizes the ipsilateral hip with one hand, while grasping the ipsilateral distal tibia with the other. The subject is asked to perform knee extension into resistance provided by the therapist, resulting in an isometric contraction. The therapist then passively flexes the knee to produce a stretch to the rectus femoris muscle.

(r) PNF to Hamstrings



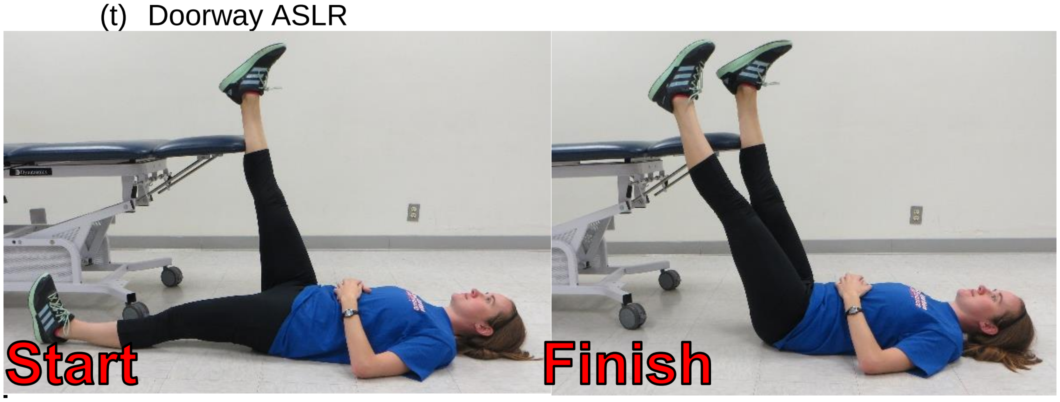
Details: The subject lies in supine, both knees extended, with the leg to be stretched supported by the therapist's shoulder. The subject performs hip extension with the ipsilateral leg into resistance provided by the therapist, resulting in an isometric contraction, while the therapist provides stabilization to the contralateral leg to maintain full knee extension. The therapist then passively flexes the ipsilateral hip with the knee extended to produce a stretch to the hamstring muscle group.

ASLR—HEP

(s) Sidelying Brettzel

Details: The subject begins in sidelying, with the leg to be stretched down on the table. The contralateral hip is flexed toward the chest and the subject grasps it with the ipsilateral hand. The ipsilateral hip is extended, with the knee flexed, and the subjects posteriorly rotates through the thoracic spine to grasp the foot with the contralateral hand to produce a stretch through the rectus femoris and iliopsoas muscles.

(t) Doorway ASLR



Details. Start: The subject lies in supine with the leg to be treated supported by a door frame or table, with hips as close to the door frame as tolerated. Finish: Maintaining full knee extension on both legs, the subject then lifts and lowers the contralateral leg.

(u) Single leg dead lift

Details: The subject begins in standing with the contralateral arm holding a kettlebell. After shifting his or her weight to the leg to be treated, the subject balances on the ipsilateral side and hinges forward to lift the contralateral leg toward the ceiling, keeping a straight line from the head to the foot. The subject then returns to standing position.

In-Line Lunge

(g) IASTM to Rectus femoris

Details: The subject lies in supine while the therapist uses an instrument to mobilize trigger points or painful areas in the rectus femoris muscle.

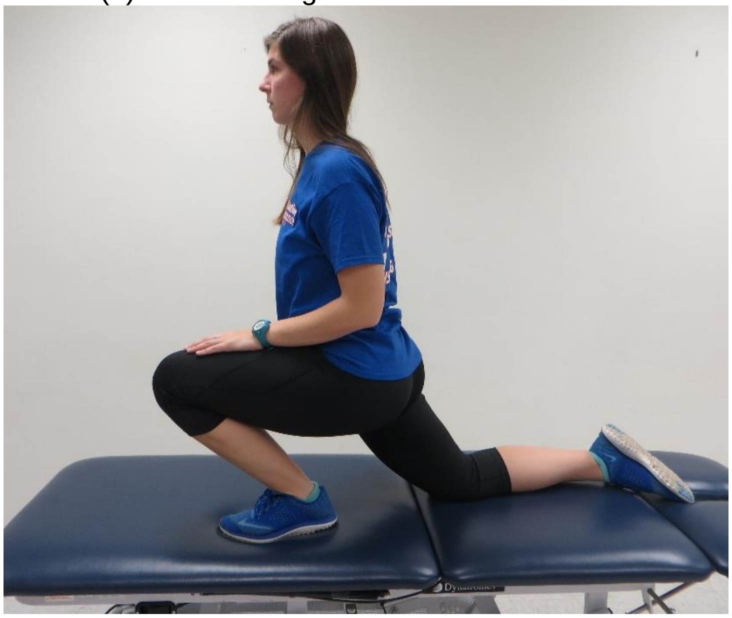
(b) IASTM—Gastroc-soleus

Details: The subject lies in prone while an instrument was used to mobilize soft tissue trigger points or painful areas in the gastrocnemius and soleus muscles.

(v) PNF to Rectus femoris

Details: The subject lies in a modified prone position, with the contralateral floor flat on the floor and the leg to be stretched on the table with the knee flexed to 90 degrees. The therapist stabilizes the ipsilateral hip with one hand, while grasping the ipsilateral distal tibia with the other. The subject is asked to perform knee extension into resistance provided by the therapist, resulting in an isometric contraction. The therapist then passively flexes the knee to produce a stretch to the rectus femoris muscle.

(d) Half kneeling dorsiflexion



Details: The subject begins in a half kneeling position, with knee and ankle flexed to 90 degrees, and leg to be treated forward. The subject shifts weight forward with an upright trunk, advancing the tibia over the toes to produce closed kinetic chain dorsiflexion.

(s) Sidelying Brettzel

Details: The subject begins in sidelying, with the leg to be stretched down on the table. The contralateral hip is flexed toward the chest and the subject grasps it with the ipsilateral hand. The ipsilateral hip is extended, with the knee flexed, and the subject posteriorly rotates through the thoracic spine to grasp the foot with the contralateral hand to produce a stretch through the rectus femoris and iliopsoas muscles.

(j) Single leg lumbar locked bridging

Details. Start: The subject begins in hooklying position with the foot of the leg to be treated flat on the table and contralateral knee flexed up toward the chest. Finish: The subject held the knee tightly toward the chest using his or her hands, while lifting the hips toward the ceiling by pushing through the heel.

Hurdle Step

(w) IASTM to Iliopsoas

Details: The subject lies in supine while the therapist palpates the medial surface of the pelvis, mobilizing trigger points or tender areas noted in the iliacus or psoas muscles.

(g) IASTM to Rectus femoris

Details: The subject lies in supine while the therapist uses an instrument to mobilize trigger points or painful areas in the rectus femoris.

PNF to Iliopsoas (x) and Rectus femoris (v)

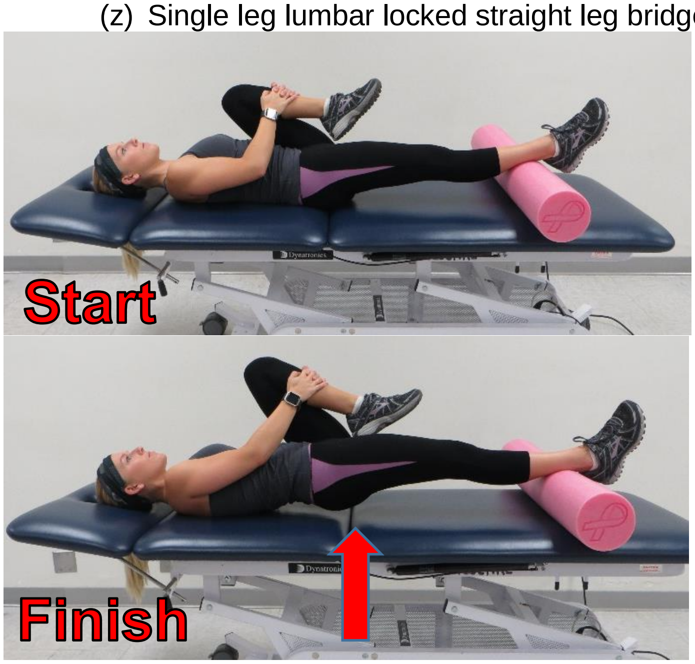
Details. <u>Iliopsoas:</u> The subject lies in a modified prone position, with the contralateral foot flat on the floor and the leg to be stretched on the table with the knee flexed comfortably. The therapist stabilizes the ipsilateral hip with one hand, while grasping the ipsilateral distal femur. The subject is asked to perform hip flexion into resistance provided by the therapist, resulting in an isometric contraction. The therapist then passively extends the hip to produce a stretch to the iliopsoas muscle group. <u>Rectus Femoris</u>: The subject and therapist positions are the same, except the therapist is grasping the distal tibia rather than distal femur. The subject is asked to perform knee extension into resistance provided by the therapist, resulting in an isometric contraction. The therapist then passively flexes the knee to produce a stretch to the rectus femoris muscle.

Hurdle Step—HEP

(y) Pigeon stretch

Details: The subject stands facing the end of a plinth with the leg to be treated supported by the plinth and positioned in 90 degrees of knee flexion and full hip external rotation and abduction. The subject is instructed to keep knee and tibia parallel with the plinth surface and a stretch should be felt in the posterior hip.

(z) Single leg lumbar locked straight leg bridge



Details. <u>Start:</u> The subject lies in supine with the leg to be treated extended and supported on a bolster, and the contralateral knee flexed to his or her chest. <u>Finish</u>: Keeping contralateral knee held tightly toward chest, the subject lifts the hips off the table, keeping ipsilateral knee extended.

(aa) Single leg Oscillatory Technique for Isometric Stabilization (OTIS)

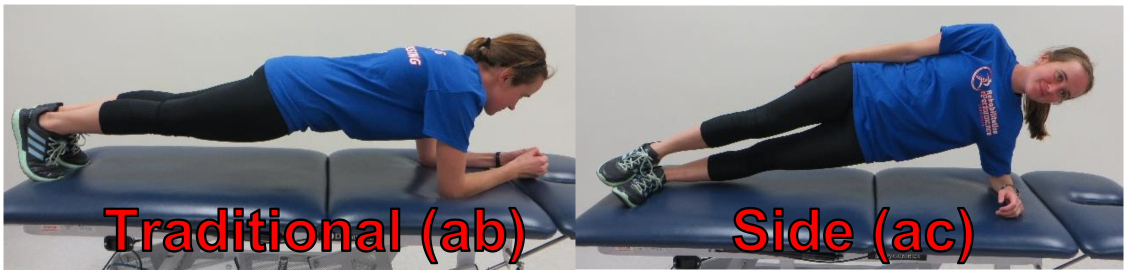
Details: The subject begins standing on the leg to be treated, with the contralateral leg raised approximately 6 inches off the floor and both arms grasping a resistance band. While maintaining balance on the ipsilateral leg, the subject rapidly and repeatedly flexes and extends the arms in a limited range to provide a perturbation to single leg balance.

Appendix F

Neuromuscular Control Interventions

Lower Quarter Neuromuscular Training

(ab-ac) Planks



Details. Traditional: The subject holds a “plank” position by propping up onto elbows and toes, keeping trunk and hips off the surface and maintaining a straight line from head to heels. Side: The subject holds a “side plank” position by propping up onto one elbow, keeping trunk and hips off the surface and maintaining a straight line from head to heels. This is repeated on the opposite side.

(ad) Pilates—Reverse Planks

Details. Start: The subject begins in a reverse plank position, propping up on hands and heels while lifting the hips off the plinth surface. Finish: The subject then alternates lifting one leg off the plinth surface, without dropping hips toward the plinth.

(ae) Pilates-Single leg stretch

Details: The subject lies in supine with his or her head elevated from the plinth surface. One knee is flexed toward chest while the other is extended approximately 45 degrees from the plinth surface. The subject alternates bringing one knee to chest while extending the other.

(af) Pilates—Bicycle

Details: The patient begins with head raised slightly off the plinth surface, with one leg extended and one knee flexed to chest. The subject alternates flexing and extending legs while twisting the contralateral elbow toward the flexed knee.

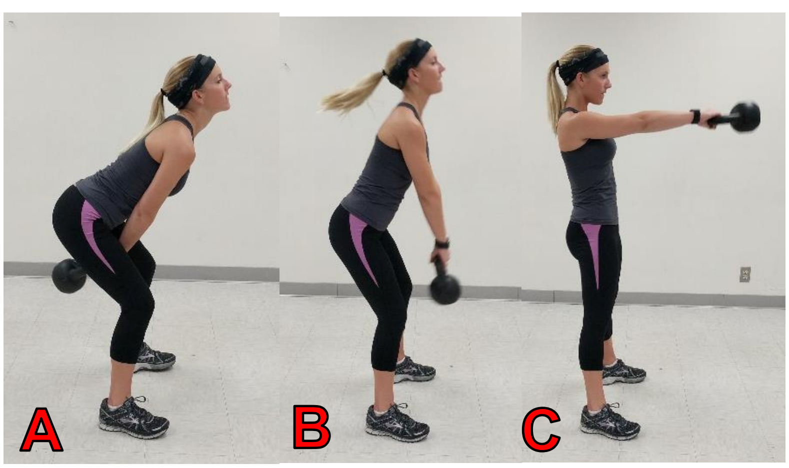
(ag) Pilates—Sidelying leg lift

Details: The subject begins in sidelying with hips perpendicular to ceiling and knees extended. Anterior: The subject lifts the top leg toward the ceiling, then advances it forward before dropping toward the front edge of the table. Posterior: The subject then raises the top leg toward the ceiling again, before reaching backwards and dropping the leg toward the back edge of the table. This is repeated on the opposite leg.

(u) Single leg dead lift

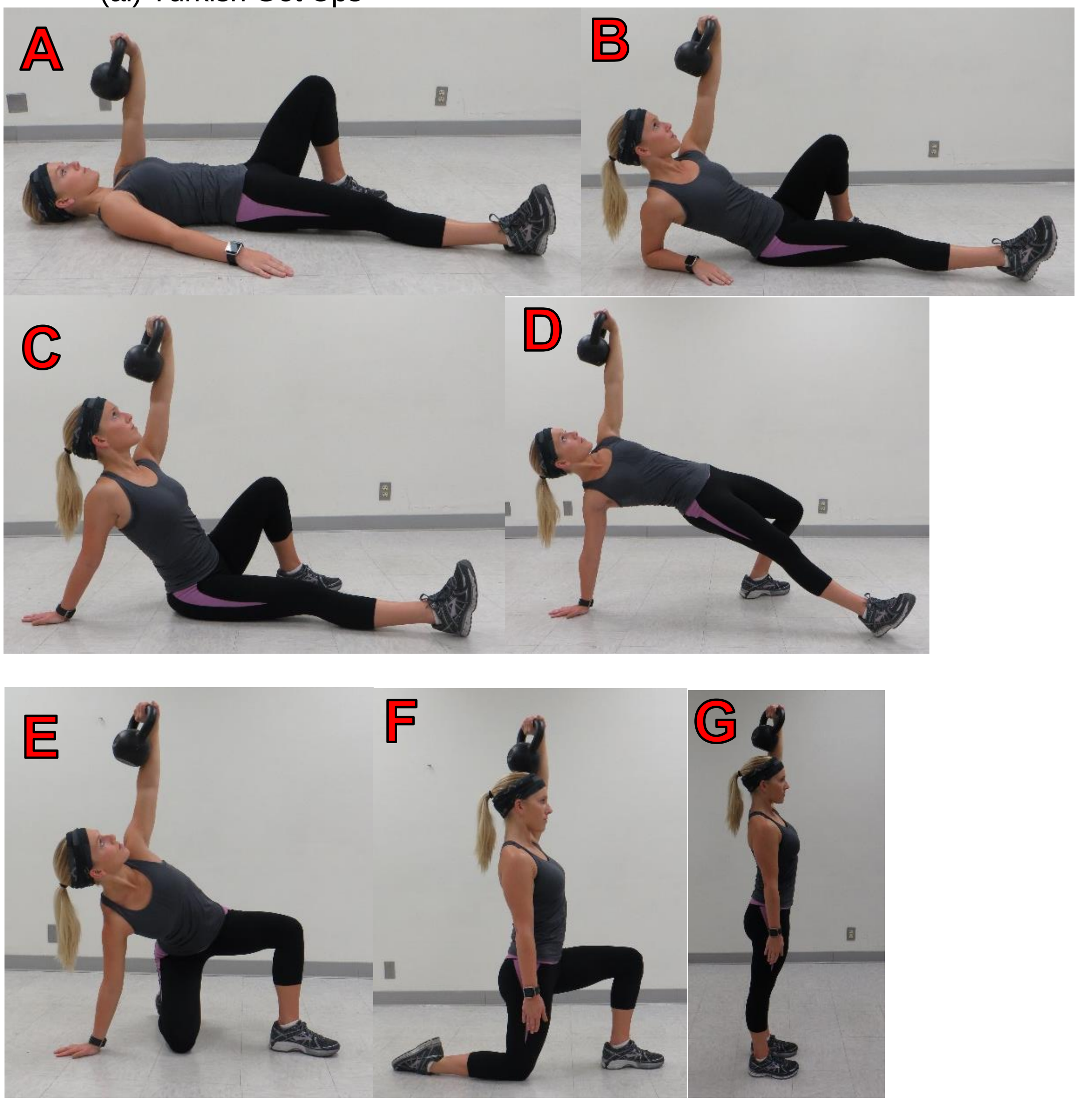
Details: The subject begins in standing with the contralateral arm holding a kettlebell. After shifting weight to the leg to be treated, the subject balances on the ipsilateral side and hinges forward to lift the contralateral leg toward the ceiling, keeping a straight line from the head to the foot. The subject then returns to standing position.

(ah) Kettlebell Swings



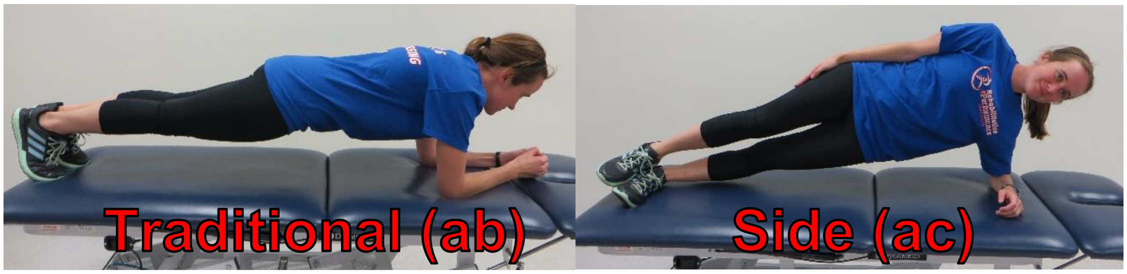
Details: The subject begins with feet shoulder width apart in a squat position and hands grasping the handles of the kettlebell on the floor. Keeping elbows straight, the subject pulls the kettlebell through the legs posteriorly (A), before quickly extending the hips (B) to swing the kettlebell toward the ceiling (C).

(ai) Turkish Get Ups



Details: The subject begins in supine with the ipsilateral knee bent and the ipsilateral arm is flexed to 90 degrees holding a kettlebell with a neutral wrist. The contralateral leg and arm are slightly abducted (A). The subject rolls up to the contralateral elbow (B), then extends the elbow to prop up into a modified long sitting position (C). The patient then lifts the hips toward the ceiling (D) before placing the contralateral knee under the hips (E). The subject then pushes the weight up toward the ceiling and rotates the contralateral leg so that he or she is now in a half kneeling position (F). Finally, the subject stands up (G), before reversing the sequence to return to a supine position.

(ab-ac) Planks



Details. Traditional: The subject holds a “plank” position by propping up onto elbows and toes, keeping trunk and hips off the surface and maintaining a straight line from head to heels. Side: The subject holds a “side plank” position by propping up onto one elbow, keeping trunk and hips off the surface and maintaining a straight line from head to heels. This is repeated on the opposite side.

(aj) Supine arm bar; (ak) Bottoms up arm bar

Details. The subject begins in hooklying with arm to be treated holding a kettlebell at 90 degrees of shoulder flexion. Supine: The bell rests against the forearm while the wrist is neutral, and the scapula is in a retracted and depressed position. Bottoms Up: The bell is facing the ceiling, balancing over the shoulder. The wrist is neutral and the scapula is retracted and depressed.

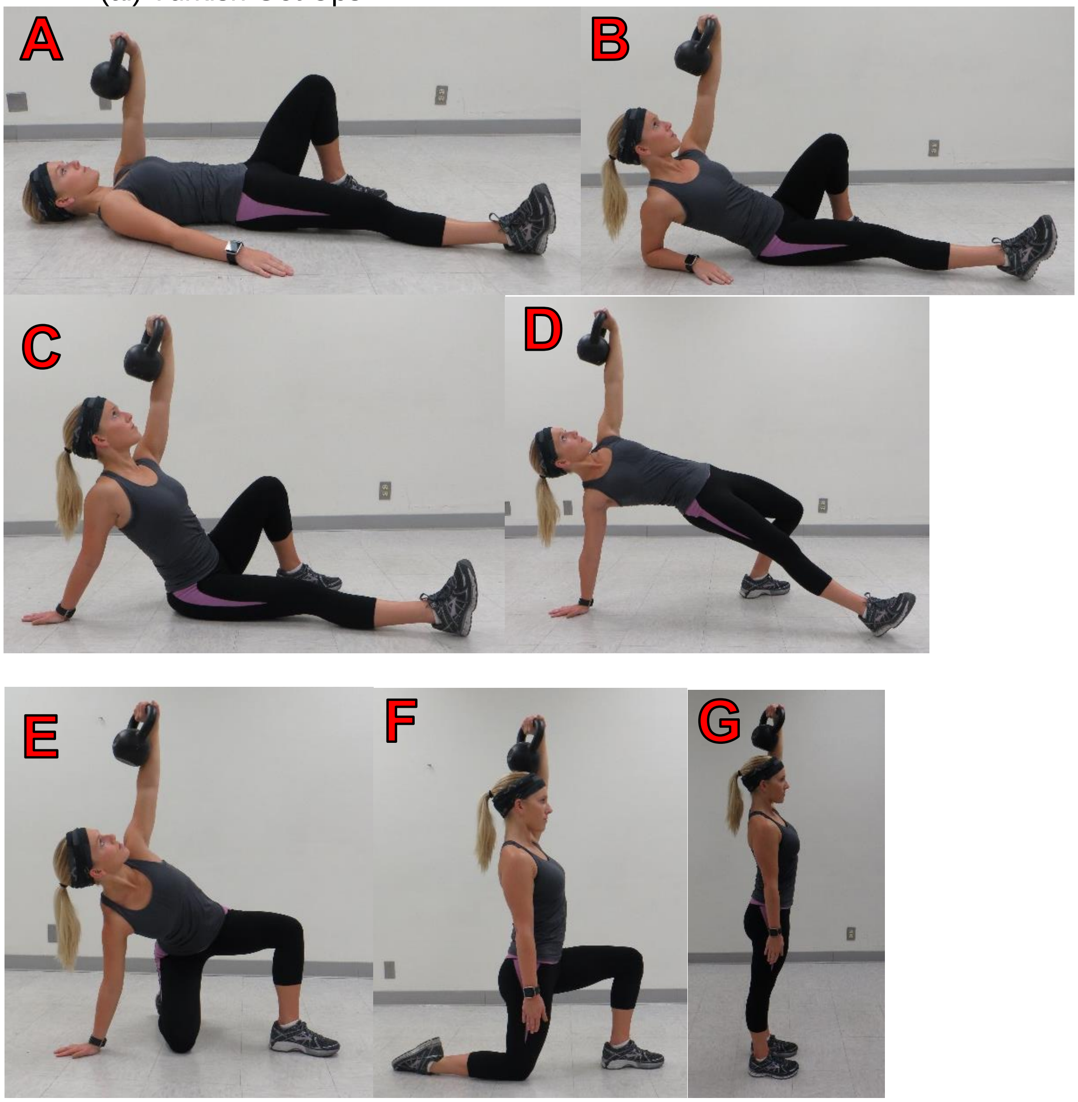
(al) Sidelying arm bar

Details: The subject begins in sidelying with hips and knees flexed to 90 degrees and arm to be treated abducted to 90 degrees. The kettlebell is balanced directly over the shoulder, with the bell resting against the forearm. The wrist is neutral and the scapula is retracted and depressed.

(am) Half kneeling press up

Details: The subject begins in half kneeling with the contralateral leg forward, knee and ankle flexed to 90 degrees. The kettlebell is held in a "rack" position, held with a neutral wrist at shoulder height and resting on the forearm (A). While maintaining an upright trunk, the subject presses the weight overhead (B).

(ai) Turkish Get Ups



Details: The subject begins in supine with the ipsilateral knee bent and the ipsilateral arm is flexed to 90 degrees holding a kettlebell with a neutral wrist. The contralateral leg and arm are slightly abducted (A). The subject rolls up to the contralateral elbow (B), then extends the elbow to prop up into a modified long sitting position (C). The patient then lifts the hips toward the ceiling (D) before placing the contralateral knee under the hips (E). The subject then pushes the weight up toward the ceiling and rotates the contralateral leg so that he or she is now in a half kneeling position (F). Finally, the subject stands up (G), before reversing the sequence to return to a supine position.

(an) 3 position kettlebell carry

Details: The subject begins in a standing position with the kettlebell held directly overhead (A). The subject walks forward in a straight path until he or she is unable to hold the kettlebell overhead, at which time it is lowered to the “rack” position (B). The subject continues to walk in a forward path until he or she is unable to hold the bell in the “rack” position, at which time the kettlebell is lowered to the side (C). The subject continues walking until he or she is unable to hold the kettlebell the side, at which time the kettlebell is lowered to the ground and the set is complete.

Appendix G

Treatment Log

Week	Session	Problem List	Pre tx measurements	Manual therapy (sets x reps)	Exercise (sets x reps)	Post tx measurements	HEP issued
1	Date:	1. 2. 3.	1. 2. 3.	1. 2. 3.	1. 2. 3. 4. 5.	1. 2. 3.	1. 2. 3.
	Date:			1. 2. 3.	1. 2. 3. 4. 5.		
2	Date:	1. 2. 3.	1. 2. 3.	1. 2. 3.	1. 2. 3. 4. 5.	1. 2. 3.	1. 2. 3.
	Date:			1. 2. 3.	1. 2. 3. 4. 5.		
3	Date:	1. 2. 3.	1. 2. 3.	1. 2. 3.	1. 2. 3. 4. 5.	1. 2. 3.	1. 2. 3.
	Date:			1. 2.	1. 2.		

				3.	**3.** **4.** **5.**		
4	**Date:**	**1.** **2.** **3.**	**1.** **2.** **3.**	**1.** **2.** **3.**	**1.** **2.** **3.** **4.** **5.**	**1.** **2.** **3.**	**1.** **2.** **3.**
	Date:			**1.** **2.** **3.**	**1.** **2.** **3.** **4.** **5.**		

Appendix H

Home Exercise Journal*

Week	Exercises Prescribed	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1								
2								
3								
4								

***Please note number of reps x sets performed daily. If exercises were not performed, please enter "N/A".**

Appendix I

	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry				
	Ankle DF ROM				
	T-spine rotation				
	Hip ER				
Fundamental Patterns	ASLR				
	HS				
	ILL				
Neuromuscular Control	YBT-LQ Ant asymmetry				
	YBT-LQ Comp				
	YBT-UQ Comp				
Pain	Pain				
	Total			True reduction in risk factors: True new risk factors: Unchanged:	**Net true change:**
Comments:					

Legend:

- Ankle DF asymmetry—ankle dorsiflexion asymmetry measured in closed kinetic chain position
- Ankle DF ROM—ankle dorsiflexion range of motion measured in closed kinetic chain position
- T-spine rotation—Thoracic rotation measured in lumbar locked position
- Hip ER—Hip external rotation, measured in prone
- ASLR—Active straight leg raise
- HS—Hurdle step

- ILL—In-line lunge
- YBT-LQ Ant asymmetry—Lower quarter Y balance test asymmetry in anterior reach direction
- YBT-LQ Comp—Lower quarter Y balance test composite score
- YBT-UQ Comp—Upper quarter Y balance test composite score
- X=in pre or post box, represents presence of that risk factor based on operational definitions. Indication in parentheses denotes on which side the risk factor was observed. An empty boxy means this factor was not present.
- Description of change: Includes pretest and posttest measures to allow for comparison to MDD and thresholds for operational definition of risk factor.
- Exceeds MDC: X in this box means the measurement exceeded MDD and may or may not have exceeded operationally defined threshold for risk factor.
- Net true change: Color coded. Green=true reduction; Blue=No change; Red=True increase.
- Comments—Narrative of thought process/rationale for decisions leading to net true change value.

Risk Factors	**Test**	**Continuous Measurement**	**Reliability**	**Other Metrics**	**Dichotomous Pass**	**Dichotomous Fail**
T-spine mobility	Lumbar locked thoracic rotation	Bubble goniometer: T-spine rotation	Intratester: ICC=.86-.90(63) Intertester: ICC=.87(63)	SEM: 2.00°-5.23° MDC: 5.53°-6.25°(63)	≥50°	<50°
Ankle mobility	Closed Kinetic Chain Dorsiflexion	Goniometer: Ankle dorsiflexion	Intraclinician: ICC=.88(64) Interclinician: ICC=.91(64)	SEM: 0.28-.41 MDC: 4.52°-4.66°(64)	Asymmetry of <5° or no asymmetry	Asymmetry of ≥5°
Ankle mobility	Closed Kinetic Chain Dorsiflexion	Goniometer: Ankle dorsiflexion	Intraclinician: ICC=.88(64) Interclinician: ICC=.91(64)	SEM: 0.28-.41 MDC: 4.52°-4.66°(64)	≥35°	<35°
Hip mobility	Prone passive ER	Goniometer: Hip ER	Intraobserver: ICC=.88(65) Interobserver:	SEM: 3.0-5.0° (14)	≥40°	<40°

			ICC=.66(65)	MDC: 8.3-13.8° (14)		
Fundamental movement	Supine active straight leg raise	Goniometer: Hip flexion	Intrarater: k_w=.60(66) Interrater: k_w=.69(66)	SEM: 0.92-0.98 MDC: 2.07-2.54(66)	Lateral malleolus of leg raised clears superior patella of contralateral leg	Lateral malleolus of leg raised does not clear superior patella of contralateral leg
Fundamental movement	Standing lunge	YBT-LQ; reach distances in cm or composite	Intrarater: k_w=.69(66) Interrater: k_w=.45(66)	SEM: 0.92-0.98 MDC: 2.07-2.54(66)	Able to complete a lunge pattern with feet 1 tibia length apart in tandem	Unable to complete lunge pattern with feet 1 tibia length apart in tandem
Fundamental movement	Standing hurdle step	YBT-LQ; reach distances in cm or composite	Intrarater: k_w=.59(66) Interrater: k_w=.67(66)	SEM: 0.92-0.98 MDC: 2.07-2.54(66)	Able to clear hurdle 1 tibia length from the floor, tap heel on the floor, then return to start position	Unable to clear hurdle 1 tibia length from the floor, tap heel on the floor, then return to start position
Core function	YBT-UQ	YBT-UQ; reach distances in cm or composite	Interrater: ICC=1.00(67)	SEM: 2.2-2.9 cm MDD: 6.1-8.1 cm(67)	Men: ≥85.1%, Women: ≥83.9%	Men: <85.1%, Women: <83.9%
Neuromuscular control	YBT-LQ	Anterior reach distance in cm	Intrarater: .82(68) Interrater: .84-.88(69)	SEM: 0.69-0.71(68) MDC: 1.91-1.97(68)	Anterior reach asymmetry of <4	Anterior reach asymmetry of ≥4 cm
Neuromuscular control	YBT-LQ	Reach distances in cm or composite	Intrarater: .82-.87(68) Interrater: .86-.91(69)	SEM: 2.08-3.31(68) MDC: 5.77-9.17(68)	>95%	≤95%

# of painful patterns	Pain with movement testing	Frequency count	---	---	No pain reported	Pain reported

Subject #: 004 **Group**: Intervention

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry				
	Ankle DF ROM				
	T-spine rotation				
	Hip ER	X	X	Pretest: R=38 Posttest: R=38	
Fundamental Patterns	ASLR				
	HS				
	ILL		X		X
Neuromuscular Control	YBT-LQ Ant asymmetry	X		Pretest: R=79.5, L=72 Posttest: R=72, L=72	X
	YBT-LQ Comp				
	YBT-UQ Comp	X (B)	X (B)	Pretest: R=69.5, L=73.8 Posttest: R=66.5, L=67.3	
Pain	Pain	X	X		
	Total	5	5	True reduction in risk factors: 1 True new risk factors: 1 Unchanged: 4	**Net true change: 0**
Comments:	Right Hip ER unchanged from pretest to posttest. Unable to complete ILL at posttest. MDC of anterior reach on YBT-LQ is 1.91 to 1.97, so change on right from pretest to posttest represents a true decrease—though now reach is symmetrical, resulting in a loss of the risk factor. MDC for YBT-UQ composite is 6.1-8.1, therefore no true change occurred in scores.				

Subject #: 006 **Group**: Intervention

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry				
	Ankle DF ROM				
	T-spine rotation				
	Hip ER	X (R)		Pretest: R=32, L=48 Posttest: R=54, L=57	X (B)
Fundamental Patterns	ASLR				
	HS				
	ILL				
Neuromuscular Control	YBT-LQ Ant asymmetry				
	YBT-LQ Comp				
	YBT-UQ Comp	X (B)	X (B)	Pretest: R=78.3, L=76.6 Posttest: R=83.6, L=83.1	X (L)
Pain	Pain				
	Total	3	2	True reduction in risk factors: 1 True new risk factors: 0 Unchanged: 2	**Net true change: -1**
Comments:	MDC of hip ER is 8.3-13.8 degrees, so true change occurred bilaterally. YBT-UQ MDC is 6.1-8.1, so likely change on left, but not on right, though both remain under 85.1 (so continues to be a risk factor)				

Subject #: 007 **Group**: Intervention

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry				
	Ankle DF ROM				
	T-spine rotation				
	Hip ER	X (B)	X (R)	Pretest: R=18, L=38 Posttest: R=33, L=40	X (R)
Fundamental Patterns	ASLR				
	HS				
	ILL				
Neuromuscular Control	YBT-LQ Ant asymmetry				
	YBT-LQ Comp				
	YBT-UQ Comp	X (L)	X (R)	Pretest: R=85.3, L=82.5 Posttest: R=83.2, L=89.2	X (L)
Pain	Pain				
	Total	3	2	True reduction in risk factors: 0 True new risk factors: 0 Unchanged: 1	**Net true change: -1**
Comments	Right Hip ER increase exceeds MDC (8.3 degrees), though still remains a risk factor (does not meet 40 threshold). Left does not exceed MDC, but left side no longer a risk factor since it meets threshold—likely not a true reduction in risk factor. MDC of YBT-UQ is 6.1-8.1, so left increase exceeds this but right decrease does not. True change on left only.				

Subject #: 009 **Group**: Intervention

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry				
	Ankle DF ROM				
	T-spine rotation	X (R)		Pretest: R=43, L=64 Posttest: R=63, L=68	X (R)
	Hip ER	X (B)		Pretest: R=33, L=24 Posttest: R=44, L=42	X (B)
Fundamental Patterns	ASLR				
	HS				
	ILL	X (L)			X
Neuromuscular Control	YBT-LQ Ant asymmetry	X	X	Pretest: R=50.5, L=61.5 Posttest: R=50, L=57	X (L)
	YBT-LQ Comp	X (B)	X (B)	Pretest: R=89.7, L=92.4 Posttest: R=83.2, L =90.2	X (R)
	YBT-UQ Comp	X (B)	X (B)	Pretest: R=75.3, L=75.3 Posttest: R=72, L=72.3	
Pain	Pain				
	Total	9	5	True reduction in risk factors: 4 True new risk factors: 0 Unchanged: 5	**Net true change: -4**
Comments:	MDC of t-spine rotation is 5.53 to 6.25, so increase on right exceeds MDC and is a true change. Hip ER increases also exceed MDC (8.3) and are a true change. MDC of YBT-LQ Ant is 1.91-1.97, so true decrease present on left and asymmetry persists. YBT-LQ comp MDC is 5.77-9.17, so decrease observed on right is likely a true decrease (left is within MDC, so both remain risk factors). YBT-UQ MDC is 6.1-8.1cm—none of the changes captured here exceed those values.				

Subject #: 010 **Group**: Intervention

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry				
	Ankle DF ROM				
	T-spine rotation	X (R)		Pretest: R=39 Posttest: R=67	X
	Hip ER	X (B)		Pretest: R=39, L=30 Posttest: R=42, L=58	X (L)
Fundamental Patterns	ASLR	X (R)		Pretest: 57 Posttest: R=71	X
	HS				
	ILL				
Neuromuscular Control	YBT-LQ Ant asymmetry				
	YBT-LQ Comp				
	YBT-UQ Comp	X (B)	X (R)	Pretest: R=83.0, L=83.9 Posttest: R=81.8, L=86	
Pain	Pain				
	Total	6	1	True reduction in risk factors: 3 True new risk factors: 0 Unchanged: 3	**Net true change: -3**
Comments:	MDC for t-spine rotation is 5.53-6.25, so change from pretest to posttest is a true change. Hip ER MDC is 8.3, so increase of 3 degrees on the right likely not a true change, though it was a borderline risk factor to begin with. Likely only true change was on left. MDC for YBT-UQ is 6.1-8.1, so changes from pretest to posttest are likely not true changes.				

Subject #: 013 **Group**: Intervention

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry				
	Ankle DF ROM				
	T-spine rotation				
	Hip ER	X (B)	X (L)	Pretest: R=22, L=27 Posttest: R=45, L=35	X (B)
Fundamental Patterns	ASLR				
	HS				
	ILL		X (L)		X
Neuromuscular Control	YBT-LQ Ant asymmetry	X		Pretest: R=68.5, L=72.5 Posttest: R=69, L=69	X (L)
	YBT-LQ Comp				
	YBT-UQ Comp	X (B)		Pretest: R=84.9, L=81.9 Posttest: R=93.2, L=90.8	X (B)
Pain	Pain				
	Total	5	2	True reduction in risk factors: 4 True new risk factors: 1 Unchanged: 1	**Net true change: -3**
Comments:	Hip ER increase on right exceeds MDC, left is borderline (8.3 degrees MDC, left change is 8 degrees) so both are likely true changes. MDC for YBT-LQ Ant is 1.91-1.97, so true decrease reach distance observed on left, which eliminated asymmetry. YBT-UQ MDC is 6.1-8.1, and both exceed this value. Cutoff for risk factor is 85.1—would not have taken much to eliminate this risk factor on right, however true change observed bilaterally.				

Subject #: 015 **Group**: Intervention

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry				
	Ankle DF ROM				
	T-spine rotation				
	Hip ER	X (L)		Pretest: L=34 Posttest: R=L=51	X (L)
Fundamental Patterns	ASLR				
	HS				
	ILL		X		X
Neuromuscular Control	YBT-LQ Ant asymmetry		X	Pretest: R=60, L=63 Posttest: R=57.5, L=63.5	X
	YBT-LQ Comp				
	YBT-UQ Comp	X (B)		Pretest: R=84.1, L=83.7 Posttest: R=93.4, L=88.6	X (R)
Pain	Pain				
	Total	3	2	True reduction in risk factors: 1 True new risk factors: 2 Unchanged: 1	**Net true change: 0**
Comments:	Increase in L Hip ER exceeds MDC (8,3 degrees), so true change occurred. MDC for anterior reach of YBT-LQ is 1.91-1.97, so true decrease occurred from pretest to posttest, creating a true asymmetry. Unable to perform ILL at posttest. MDC of YBT-UQ is 6.1-8.1, so improvement on the right represents a true change, while left does not. Additionally, passing for males on the YBT-UQ was 85.1, so a minimal change in the measurement would have caused him to eliminate this risk factor, since both scores were borderline at pretest.				

Subject #: 021 **Group**: Intervention

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry				
	Ankle DF ROM				
	T-spine rotation				
	Hip ER	X (B)		Pretest: R=30 L=35 Posttest: R=50, L=52	X (B)
Fundamental Patterns	ASLR				
	HS				
	ILL				
Neuromuscular Control	YBT-LQ Ant asymmetry				
	YBT-LQ Comp				
	YBT-UQ Comp	X (R)	X (R)	Pretest: R=84.3, L=91.2 Posttest: R=84, L=90.7	
Pain	Pain	X	X		
	Total	4	2	True reduction in risk factors: 2 True new risk factors: 0 Unchanged: 2	**Net true change: -2**
Comments:	Hip ER increases exceeds MDC of (8.3 degrees), so true change occurred bilaterally. Right UQ measurements unchanged from pre to posttest. Lower back pain persisted from pre to posttest.				

Subject #: 024 **Group**: Intervention

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry				
	Ankle DF ROM				
	T-spine rotation	X (B)		Pretest: R=38, L=31 Posttest: R=62, L=56	X (B)
	Hip ER	X (B)		Pretest: R=37, L=35 Posttest: R=51, L=45	X (B)
Fundamental Patterns	ASLR				
	HS				
	ILL				
Neuromuscular Control	YBT-LQ Ant asymmetry	X		Pretest: R=60, L=56 Posttest: R=57, L=54	X
	YBT-LQ Comp				
	YBT-UQ Comp				
Pain	Pain	X	X	Pretest: R knee during YBT-LQ Posttest: R shoulder/elbow during YBT-UQ	
	Total	6	1	True reduction in risk factors: 5 True new risk factors: 0 Unchanged: 1 (pain still present)	**Net true change: -5**
Comments:	T-spine MDC 5.53-6.25, so changes from pre to posttest are true changes bilaterally. Hip ER changes also exceed MDC of 8.3 degrees, so changes are also true changes. Ant asymmetry reaches exceed MDC (1.91-1.97), so true decrease in reach distance observed, which potentially eliminated the risk factor. Knee pain eliminated, but new onset shoulder pain present during posttesting (due to increase in t-spine mobility?)				

Subject #: 028 **Group**: Intervention

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry				
	Ankle DF ROM				
	T-spine rotation				
	Hip ER	X (B)		Pretest: R=34, L=37 Posttest: R=43, L=49	X (B)
Fundamental Patterns	ASLR				
	HS				
	ILL				
Neuromuscular Control	YBT-LQ Ant asymmetry				
	YBT-LQ Comp				
	YBT-UQ Comp	X		Pretest: R=81, L=77.6 Posttest: R=87, L=90.1	X (B)
Pain	Pain				
	Total	3	0	True reduction in risk factors: 3 True new risk factors: 0 Unchanged: 0	**Net true change: -3**
Comments:	Hip ER increase exceeds MDC of 8.3 degrees, so true increase bilaterally. YBT-UQ MDD is 6.1-8.1, so right increase is borderline, but left is a true change.				

Subject #: 029 **Group**: Intervention

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry	X		Pretest: R=30, L=40 Posttest: R=40, L=43	X (R)
	Ankle DF ROM	X		See above	X (R)
	T-spine rotation				
	Hip ER				
Fundamental Patterns	ASLR				
	HS				
	ILL	X (B)			X (B)
Neuromuscular Control	YBT-LQ Ant asymmetry				
	YBT-LQ Comp	X		Pretest: R=94.9 Posttest: R=99.1	
	YBT-UQ Comp	X (B)	X (B)	Pretest: R=70.4, L=73 Posttest: R=66.7, L=73.6	
Pain	Pain				
	Total	7	2	True reduction in risk factors: 4 True new risk factors: 0 Unchanged: 3	**Net true change: -4**
Comments:	MDC of CKC DF is 4.52-4.66, so true change observed on right, probably not on left. MDC of YBT-LQ Comp is 5.77-9.17, so improvement in R from pretest to posttest is likely not a true change. The cutoff for composite score was 95%, so this risk factor was borderline and likely not present at pretest. MDC of YBT-UQ is 6.1-8.1 cm, so no true change observed with YBT-UQ.				

Subject #: 033 **Group**: Intervention

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry				
	Ankle DF ROM	X (L)		Pretest: R=35, L=34 Posttest: R=38, L=39	X (L)
	T-spine rotation	X		Pretest: R=41, L=51 Posttest: R=62, L=64	X (B)
	Hip ER	X (B)	X (B)	Pretest: R=29, L=31 Posttest: R=37, L=37	X (B)
Fundamental Patterns	ASLR				
	HS				
	ILL				
Neuromuscular Control	YBT-LQ Ant asymmetry				
	YBT-LQ Comp				
	YBT-UQ Comp	X (B)		Pretest: R=80.1, L=83.5 Posttest: R=84.8, L=86.4	
Pain	Pain	X		Right shoulder blade at pretest; none posttest	
	Total	7	2	True reduction in risk factors: 3 True new risk factors: 0 Unchanged: 4	**Net true change: -3**
Comments:	MDC for CKC DF is 4.52-4.66, so true change observe on left. MDC for t-spine rotation is 5.53-6.25, so increased observed are true changes bilaterally. Changes in hip ER are 8 or less degrees bilaterally, with an MDC of 8.3 degrees. Likely a true change on the right, but not on the left—regardless, ROM still under threshold of 40 so risk factor persists bilat. Threshold for passing YBT-UQ for females was 83.9, so it wouldn't have taken				

	much to eliminate this risk factor bilaterally. MDC for YBT-UQ is 6.1-8.1 cm, so changes observed fall within MDC—likely not true changes.

Subject #: 034 **Group**: Intervention

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry	X		Pretest: R=43, L=49 Posttest: R=43, L=45	X?
	Ankle DF ROM				
	T-spine rotation	X (R)		Pretest: R=48, L=69 Posttest: R=63, L=65	X (R)
	Hip ER	X (L)	X (L)	Pretest: R=43, L=30 Posttest: R=41, L=30	
Fundamental Patterns	ASLR				
	HS				
	ILL				
Neuromuscular Control	YBT-LQ Ant asymmetry				
	YBT-LQ Comp				
	YBT-UQ Comp				
Pain	Pain				
	Total	3	1	True reduction in risk factors: 1 True new risk factors: 0 Unchanged: 2	**Net true change: -1**
Comments:	MDC of CKC DF is 4.52-4.66, so decrease in ankle DF on left is borderline—though this eliminated the asymmetry. MDC of t-spine if 5.53-6.25, so increase in right t-spine motion is true change and reduction is not likely a true change. Hip ER essentially stayed the same.				

Appendix J

Subject #: 001 **Group**: Control

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry				
	Ankle DF ROM				
	T-spine rotation				
	Hip ER	X (L)	X (R)	Pretest: R=42, L=29 Posttest: R=27, L=42	X (R)
Fundamental Patterns	ASLR				
	HS				
	ILL		X (B)	Unable to perform bilaterally due to pain	X (B)
Neuromuscular Control	YBT-LQ Ant asymmetry		X	Unable to perform anterior reach due to pain	
	YBT-LQ Comp		X (R & L)	Composite score substantially decreased due to inability to perform anterior reach	X (B)
	YBT-UQ Comp				
Pain	Pain	X	X		X
	Total	2	6	True reduction in risk factors: 1 True new risk factors: 6 Unchanged: 1	**Net true change: +4**
Comments:	MDC of hip ER is 8.3-13.8. Therefore, changes from pre to posttest exceed error. Left hip truly increased, and right hip truly decreased.				

Subject #: 003 **Group**: Control

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry				
	Ankle DF ROM				
	T-spine rotation				
	Hip ER				
Fundamental Patterns	ASLR				
	HS				
	ILL	X (L)			X
Neuromuscular Control	YBT-LQ Ant asymmetry	X		Pretest: R=69, L=78 Posttest: R=69, L=71	X
	YBT-LQ Comp				
	YBT-UQ Comp				
Pain	Pain				
	Total	2	0	True reduction in risk factors: 2 True new risk factors: 0 Unchanged: 0	**Net true change: -2**
Comments:	Anterior reach on left decreased by 7 cm MDD is ~2 (1.91-1.97), so represents a true change (meaning anterior reach on left truly decreased from pretest to posttest).				

Subject #: 008 **Group**: Control

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry				
	Ankle DF ROM				
	T-spine rotation				
	Hip ER	X (B)	X (B)	Pretest: R=24, L=30 Posttest: R=35, L=38	X (B)
Fundamental Patterns	ASLR				
	HS				
	ILL				
Neuromuscular Control	YBT-LQ Ant asymmetry				
	YBT-LQ Comp				
	YBT-UQ Comp				
Pain	Pain				
	Total	2	2	True reduction in risk factors: 0 True new risk factors: 0 Unchanged: 1	**Net true change: 0**
Comments:	Increase in hip ER on right exceeds MDC, right is borderline (MDC=8.3-13.8 degrees. Changes observed bilaterally represent a true change, though still below 40 degree threshold (therefore risk factor still present).				

Subject #: 011 **Group**: Control

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry		X	Pretest: R=40, L=39 Posttest: R=41, L=33	X (L)
	Ankle DF ROM		X (L)	See above. Difference between sides exceeds 5 degrees, and change is likely a true change.	X (L)
	T-spine rotation		X (B)	Pretest: R=73, L=62 Posttest: R=42, L=44	X (B)
	Hip ER	X (L)		Pretest: R=41, L=33 Posttest: R=52, L=58	X (B)
Fundamental Patterns	ASLR				
	HS				
	ILL				
Neuromuscular Control	YBT-LQ Ant asymmetry	X	X	Pretest: 68.5 right, 62.5 left. Posttest: 66.5 right, 60.5 left.	X (B)
	YBT-LQ Comp				
	YBT-UQ Comp	X (B)		Pretest: R=80.2, L=80.4 Posttest: R=88.6, L=90.5	X (L, and probably R)
Pain	Pain		X		X
	Total	4	6	True reduction in risk factors: 3 True new risk factors: 5 Unchanged: 1	**Net true change: +1**
Comments:	Left ankle DF decrease exceeds MDC (4.52-4.66 degrees), so true decrease from pretest to posttest; Hip ER increase exceeds MDC of 8.3-13.8 degrees bilaterally from pretest to posttest. Anterior asymmetry exceeds MDC (1.91-1.97) from pre to posttest. T-spine mobility MDC is 5.53-6.25 degrees, so true decrease in t-spine mobility from pre to post test. YBT-UQ MDC is 6.1-8.1 cm, so changes from pre to posttest represent true increases.				

Subject #: 012 **Group**: Control

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry		X	Pretest: R=33, L=36 Posttest: R=33, L=40	X??
	Ankle DF ROM	X (R)	X (R)	Right ankle DF 33 at pretest and posttest	
	T-spine rotation				
	Hip ER	X (B)		Pretest: R=38, L=34 Posttest: R=54, L=58	X
Fundamental Patterns	ASLR		X (L)	Pretest: 88 degrees bilat Posttest: R=70, L=65	X (B)
	HS				
	ILL				
Neuromuscular Control	YBT-LQ Ant asymmetry		X	Pretest: R=78, L=80 Posttest: R=71, L=76.5	X (B)
	YBT-LQ Comp				
	YBT-UQ Comp				
Pain	Pain				
	Total	3	4	True reduction in risk factors: 2 True new risk factors: 3 Unchanged: 1	**Net true change: +1**
Comments	Difference in ankle DF on left from pre to posttest is right around MDC (4.52-4.66), however difference between R and L at posttest is a true difference. Right ankle did not change from pre to posttest. Bilat increase in Hip ER exceeds MDC of 8.3-13.8 degrees and is a true change. ASLR changes represents true decrease bilaterally. YBT-LQ Ant reach decreased by 7cm MDC is 1.91-1.97, so represents a true decrease bilaterally.				

Subject #: 014 **Group**: Control

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry		X	Pretest: R=43, L=42 Posttest: R=47, L=39	X
	Ankle DF ROM				
	T-spine rotation	X (L)		Pretest: R=62, L=47 Posttest: R=61, L=56	X (L)
	Hip ER	X (B)	X (L)	Pretest: R=34, L=30 Posttest: R=40, L=37	
Fundamental Patterns	ASLR				
	HS				
	ILL				
Neuromuscular Control	YBT-LQ Ant asymmetry				
	YBT-LQ Comp				
	YBT-UQ Comp				
Pain	Pain				
	Total	3	2	True reduction in risk factors: 1 True new risk factors: 1 Unchanged: 2	**Net true change: 0**
Comments:	Increase in right CKC DF is right around MDC (4.52-4.66 degrees), left does not exceed MDC, however difference between measures exceeds MDC, so a true increase on right may have occurred, and a true asymmetry is observed. MDC of t-spine rotation is 5.53-6.25, so no change on right, but true increase likely from pre to posttest on left. Increase in Hip ER is under MDC of 8.3 degrees, and is therefore not a true change (still under 40 degree threshold though, so continues to be a risk factor).				

Subject #: 016 **Group**: Control

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry				
	Ankle DF ROM				
	T-spine rotation	X (B)	X	Pretest: R=49, L=45 Posttest: R=47, L=54	X (L)
	Hip ER				
Fundamental Patterns	ASLR				
	HS				
	ILL				
Neuromuscular Control	YBT-LQ Ant asymmetry	X		Pretest: R=83, L=77 Posttest: R=69, L=70	X
	YBT-LQ Comp				
	YBT-UQ Comp				
Pain	Pain				
	Total	3	1	True reduction in risk factors: 2 True new risk factors: 0 Unchanged: 1	**Net true change: -2**
Comments:	Right t-spine unchanged, however left t-spine represents true increase (MDC is 5.53-6.25). MDC for YBT-LQ Ant is 1.91-1.97, so though Ant asymmetry is eliminated posttest, decreases on R and left are true decreases in reach distance. Right likely represents a true decrease, and left is a true decrease. Right composite YBT-LQ decrease exceeded MDC (117.4 to 103.7), however still well above 95% threshold. Left decrease is within MDC (111.7 to 106), but again still well above the 95% cutoff.				

Subject #: 019 **Group**: Control

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry				
	Ankle DF ROM				
	T-spine rotation				
	Hip ER				
Fundamental Patterns	ASLR				
	HS				
	ILL				
Neuromuscular Control	YBT-LQ Ant asymmetry				
	YBT-LQ Comp				
	YBT-UQ Comp	X (R)		Pretest: R=85, L=91.2 Posttest: R=89.5, L=90.8	
Pain	Pain				
	Total	1	0	True reduction in risk factors: 3 True new risk factors: 5 Unchanged: 1	**Net true change: 0**
Comments:	Threshold for males on YBT-UQ was 85.1, so right narrowly missed the cutoff. MDD for YBT-UQ is 6.1-8.1cm, so likely no true changes occurred from pretest to posttest. This risk factor likely was not present at pretest.				

Subject #: 020 **Group**: Control

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry				
	Ankle DF ROM				
	T-spine rotation				
	Hip ER	X (L)	X (B)	Pretest: R=41, L=38 Posttest: R=38, L=38	
Fundamental Patterns	ASLR				
	HS				
	ILL				
Neuromuscular Control	YBT-LQ Ant asymmetry				
	YBT-LQ Comp				
	YBT-UQ Comp				
Pain	Pain				
	Total	1	2	True reduction in risk factors: 0 True new risk factors: 0 Unchanged: 1	**Net true change: 0**
Comments:	Difference between pretest and posttest measures is within MDC of 8.3 degrees, meaning no true change occurred. Hip ER is likely a borderline risk factor for this subject—given that this is his only risk factor, overall he is still at a low risk for injury.				

Subject #: 032 **Group**: Control

Risk Category	Risk Factors	Pre	Post	Description of Change	Exceeds MDC
Mobility	Ankle DF asymmetry				
	Ankle DF ROM				
	T-spine rotation				
	Hip ER	X (B)	X (L)	Pretest: R=21, L=21 Posttest: R=45, L=31	X (B)
Fundamental Patterns	ASLR				
	HS				
	ILL				
Neuromuscular Control	YBT-LQ Ant asymmetry				
	YBT-LQ Comp				
	YBT-UQ Comp				
Pain	Pain	X		Reported L ankle pain. No pain reported posttest.	X
	Total	3	1	True reduction in risk factors: 2 True new risk factors: Unchanged: 1	**Net true change: -2**
Comments:	Increase in hip ER exceeds MDC of 8.3-13.8 degrees, so true increase occurred bilaterally (L still under 40 threshold so continues to be a risk factor).				

References

1. Chandran A, Barron MJ, Westerman BJ, DiPietro L. Time Trends in Incidence and Severity of Injury Among Collegiate Soccer Players in the United States: NCAA Injury Surveillance System, 1990-1996 and 2004-2009. Am J Sports Med 2016;44(12):3237-3242.
2. Donnell-Fink LA, Klara K, Collins JE, Yang HY, Goczalk MG, Katz JN, et al. Effectiveness of Knee Injury and Anterior Cruciate Ligament Tear Prevention Programs: A Meta-Analysis. PLoS One 2015;10(12):e0144063.
3. Verrall GM, Slavotinek JP, Barnes PG, Esterman A, Oakeshott RD, Spriggins AJ. Hip joint range of motion restriction precedes athletic chronic groin injury. J Sci Med Sport 2007;10(6):463-6.
4. de Noronha M, Refshauge KM, Herbert RD, Kilbreath SL, Hertel J. Do voluntary strength, proprioception, range of motion, or postural sway predict occurrence of lateral ankle sprain? Br J Sports Med 2006;40(10):824-8; discussion 828.
5. Teyhen DS, Shaffer SW, Butler RJ, Goffar SL, Kiesel KB, Rhon DI, et al. What Risk Factors Are Associated With Musculoskeletal Injury in US Army Rangers? A Prospective Prognostic Study. Clin Orthop Relat Res 2015;473(9):2948-58.
6. Kiesel KB, Butler RJ, Plisky PJ. Prediction of injury by limited and asymmetrical fundamental movement patterns in american football players. J Sport Rehabil 2014;23(2):88-94.
7. Mokha M, Sprague PA, Gatens DR. Predicting Musculoskeletal Injury in National Collegiate Athletic Association Division II Athletes From Asymmetries and Individual-Test Versus Composite Functional Movement Screen Scores. J Athl Train 2016;51(4):276-82.
8. Plisky PJ, Rauh MJ, Kaminski TW, Underwood FB. Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. J Orthop Sports Phys Ther 2006;36(12):911-9.
9. Gribble PA, Terada M, Beard MQ, Kosik KB, Lepley AS, McCann RS, et al. Prediction of Lateral Ankle Sprains in Football Players Based on Clinical Tests and Body Mass Index. Am J Sports Med 2016;44(2):460-7.
10. Bushman TT, Grier TL, Canham-Chervak MC, Anderson MK, North WJ, Jones BH. Pain on Functional Movement Screen Tests and Injury Risk. J Strength Cond Res 2015;29 Suppl 11:S65-70.
11. Zazulak BT, Hewett TE, Reeves NP, Goldberg B, Cholewicki J. Deficits in neuromuscular control of the trunk predict knee injury risk: a prospective biomechanical-epidemiologic study. Am J Sports Med 2007;35(7):1123-30.
12. Wilkerson GB, Giles JL, Seibel DK. Prediction of core and lower extremity strains and sprains in collegiate football players: a preliminary study. J Athl Train 2012;47(3):264-72.
13. Perry J, Burnfield JM. Gait analysis : normal and pathological function. 2nd ed. ed. Thorofare, N.J.: SLACK; 2010.
14. de la Motte S, Arnold BL, Ross SE. Trunk-rotation differences at maximal reach of the star excursion balance test in participants with chronic ankle instability. J Athl Train 2015;50(4):358-65.
15. Barengo NC, Meneses-Echavez JF, Ramirez-Velez R, Cohen DD, Tovar G, Bautista JE. The impact of the FIFA 11+ training program on injury prevention in football players: a systematic review. Int J Environ Res Public Health 2014;11(11):11986-2000.
16. Heubner BR, Mindy; Alm, Ashley, Matsel, Kyle. A pre-season injury prevention training program improves movement test scores and injury risk category. 2012.

17. Lehr ME, Plisky PJ, Butler RJ, Fink ML, Kiesel KB, Underwood FB. Field-expedient screening and injury risk algorithm categories as predictors of noncontact lower extremity injury. Scand J Med Sci Sports 2013;23(4):e225-32.
18. Kunz M. 265 million playing football. Fifa.com. http://www.fifa.com/mm/document/fifafacts/bcoffsurv/emaga_9384_10704.pdf. Published July 2007. Accessed June 14, 2017.
19. Leventer L, Eek F, Hofstetter S, Lames M. Injury Patterns among Elite Football Players: A Media-based Analysis over 6 Seasons with Emphasis on Playing Position. Int J Sports Med 2016;37(11):898-908.
20. Stubbe JH, van Beijsterveldt AM, van der Knaap S, Stege J, Verhagen EA, van Mechelen W, et al. Injuries in professional male soccer players in the Netherlands: a prospective cohort study. J Athl Train 2015;50(2):211-6.
21. Read PJ, Oliver JL, De Ste Croix MB, Myer GD, Lloyd RS. Neuromuscular Risk Factors for Knee and Ankle Ligament Injuries in Male Youth Soccer Players. Sports Med 2016;46(8):1059-66.
22. von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP, et al. [The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting of observational studies]. Internist (Berl) 2008;49(6):688-93.
23. Bradley PS, Portas MD. The relationship between preseason range of motion and muscle strain injury in elite soccer players. J Strength Cond Res 2007;21(4):1155-9.
24. Clausen MB, Tang L, Zebis MK, Krustrup P, Holmich P, Wedderkopp N, et al. Self-reported previous knee injury and low knee function increase knee injury risk in adolescent female football. Scand J Med Sci Sports 2016;26(8):919-26.
25. Engebretsen AH, Myklebust G, Holme I, Engebretsen L, Bahr R. Intrinsic risk factors for acute ankle injuries among male soccer players: a prospective cohort study. Scand J Med Sci Sports 2010;20(3):403-10.
26. Engebretsen AH, Myklebust G, Holme I, Engebretsen L, Bahr R. Intrinsic risk factors for groin injuries among male soccer players: a prospective cohort study. Am J Sports Med 2010;38(10):2051-7.
27. Engebretsen AH, Myklebust G, Holme I, Engebretsen L, Bahr R. Intrinsic risk factors for acute knee injuries among male football players: a prospective cohort study. Scand J Med Sci Sports 2011;21(5):645-52.
28. Engebretsen AH, Myklebust G, Holme I, Engebretsen L, Bahr R. Intrinsic risk factors for hamstring injuries among male soccer players: a prospective cohort study. Am J Sports Med 2010;38(6):1147-53.
29. Fousekis K, Tsepis E, Poulmedis P, Athanasopoulos S, Vagenas G. Intrinsic risk factors of non-contact quadriceps and hamstring strains in soccer: a prospective study of 100 professional players. Br J Sports Med 2011;45(9):709-14.
30. Gonell AC, Romero JA, Soler LM. Relationship between the Y Balance Test Scores and Soft Tissue Injury Incidence in a Soccer Team. Int J Sports Phys Ther 2015;10(7):955-66.
31. Henry T, Evans K, Snodgrass SJ, Miller A, Callister R. Risk Factors for Noncontact Ankle Injuries in Amateur Male Soccer Players: A Prospective Cohort Study. Clin J Sport Med 2016;26(3):251-8.
32. Bennell KL, Talbot RC, Wajswelner H, Techovanich W, Kelly DH, Hall AJ. Intra-rater and inter-rater reliability of a weight-bearing lunge measure of ankle dorsiflexion. Aust J Physiother 1998;44(3):175-180.

33. Nilstad A, Andersen TE, Bahr R, Holme I, Steffen K. Risk factors for lower extremity injuries in elite female soccer players. Am J Sports Med 2014;42(4):940-8.
34. Ford KR, Myer GD, Hewett TE. Reliability of landing 3D motion analysis: implications for longitudinal analyses. Med Sci Sports Exerc 2007;39(11):2021-8.
35. Steffen K, Myklebust G, Andersen TE, Holme I, Bahr R. Self-reported injury history and lower limb function as risk factors for injuries in female youth soccer. Am J Sports Med 2008;36(4):700-8.
36. van Dyk N, Bahr R, Whiteley R, Tol JL, Kumar BD, Hamilton B, et al. Hamstring and Quadriceps Isokinetic Strength Deficits Are Weak Risk Factors for Hamstring Strain Injuries: A 4-Year Cohort Study. Am J Sports Med 2016;44(7):1789-95.
37. Kofotolis N, Kellis E. Ankle sprain injuries: a 2-year prospective cohort study in female Greek professional basketball players. J Athl Train 2007;42(3):388-94.
38. Chorba RS, Chorba DJ, Bouillon LE, Overmyer CA, Landis JA. Use of a functional movement screening tool to determine injury risk in female collegiate athletes. N Am J Sports Phys Ther 2010;5(2):47-54.
39. Bonazza NA, Smuin D, Onks CA, Silvis ML, Dhawan A. Reliability, Validity, and Injury Predictive Value of the Functional Movement Screen: A Systematic Review and Meta-analysis. Am J Sports Med 2016.
40. Collins NJ, Prinsen CA, Christensen R, Bartels EM, Terwee CB, Roos EM. Knee Injury and Osteoarthritis Outcome Score (KOOS): systematic review and meta-analysis of measurement properties. Osteoarthritis Cartilage 2016;24(8):1317-29.
41. Dallinga JM, Benjaminse A, Lemmink KA. Which screening tools can predict injury to the lower extremities in team sports?: a systematic review. Sports Med 2012;42(9):791-815.
42. Hoch MC, Staton GS, McKeon PO. Dorsiflexion range of motion significantly influences dynamic balance. J Sci Med Sport 2011;14(1):90-2.
43. Butler RJ, Lehr ME, Fink ML, Kiesel KB, Plisky PJ. Dynamic balance performance and noncontact lower extremity injury in college football players: an initial study. Sports Health 2013;5(5):417-22.
44. Smith CA, Chimera NJ, Warren M. Association of y balance test reach asymmetry and injury in division I athletes. Med Sci Sports Exerc 2015;47(1):136-41.
45. Knapik JJ, Spiess A, Swedler D, Grier T, Hauret K, Yoder J, et al. Retrospective examination of injuries and physical fitness during Federal Bureau of Investigation new agent training. J Occup Med Toxicol 2011;6:26.
46. Lisman P, O'Connor FG, Deuster PA, Knapik JJ. Functional movement screen and aerobic fitness predict injuries in military training. Med Sci Sports Exerc 2013;45(4):636-43.
47. Sefton JM, Lohse KR, McAdam JS. Prediction of Injuries and Injury Types in Army Basic Training, Infantry, Armor, and Cavalry Trainees Using a Common Fitness Screen. J Athl Train 2016;51(11):849-857.
48. Rossler R, Donath L, Bizzini M, Faude O. A new injury prevention programme for children's football--FIFA 11+ Kids--can improve motor performance: a cluster-randomised controlled trial. J Sports Sci 2016;34(6):549-56.
49. Chimera NJ, Warren M. Use of clinical movement screening tests to predict injury in sport. World J Orthop 2016;7(4):202-17.
50. HJ R. Effects of immobilization of various body segments on energy cost of human locomotion. Ergonomics Suppl 1965;53.
51. Smith T, Gilleard W. Three-dimensional analysis of a lofted instep kick by male and female footballers. Eur J Sport Sci 2016;16(1):57-64.

52. Fullenkamp AM, Campbell BM, Laurent CM, Lane AP. The Contribution of Trunk Axial Kinematics to Poststrike Ball Velocity During Maximal Instep Soccer Kicking. J Appl Biomech 2015;31(5):370-6.
53. Shan G, Westerhoff P. Full-body kinematic characteristics of the maximal instep soccer kick by male soccer players and parameters related to kick quality. Sports Biomech 2005;4(1):59-72.
54. van Beijsterveldt AM, Stubbe JH, Schmikli SL, van de Port IG, Backx FJ. Differences in injury risk and characteristics between Dutch amateur and professional soccer players. J Sci Med Sport 2015;18(2):145-9.
55. Prodromos CC, Han Y, Rogowski J, Joyce B, Shi K. A meta-analysis of the incidence of anterior cruciate ligament tears as a function of gender, sport, and a knee injury-reduction regimen. Arthroscopy 2007;23(12):1320-1325 e6.
56. Price MJ, Tuca M, Cordasco FA, Green DW. Nonmodifiable risk factors for anterior cruciate ligament injury. Curr Opin Pediatr 2017;29(1):55-64.
57. Al Attar WS, Soomro N, Pappas E, Sinclair PJ, Sanders RH. How Effective are F-MARC Injury Prevention Programs for Soccer Players? A Systematic Review and Meta-Analysis. Sports Med 2016;46(2):205-17.
58. Cruz-Diaz D, Lomas Vega R, Osuna-Perez MC, Hita-Contreras F, Martinez-Amat A. Effects of joint mobilization on chronic ankle instability: a randomized controlled trial. Disabil Rehabil 2015;37(7):601-10.
59. Loudon JK, Reiman MP, Sylvain J. The efficacy of manual joint mobilisation/manipulation in treatment of lateral ankle sprains: a systematic review. Br J Sports Med 2014;48(5):365-70.
60. Markovic G. Acute effects of instrument assisted soft tissue mobilization vs. foam rolling on knee and hip range of motion in soccer players. J Bodyw Mov Ther 2015;19(4):690-6.
61. Kelly S, Beardsley C. Specific and Cross-over Effects of Foam Rolling on Ankle Dorsiflexion Range of Motion. Int J Sports Phys Ther 2016;11(4):544-51.
62. Mohr AR, Long BC, Goad CL. Effect of foam rolling and static stretching on passive hip-flexion range of motion. J Sport Rehabil 2014;23(4):296-9.
63. Johnson KD, Kim KM, Yu BK, Saliba SA, Grindstaff TL. Reliability of thoracic spine rotation range-of-motion measurements in healthy adults. J Athl Train 2012;47(1):52-60.
64. Powden CJ, Hoch JM, Hoch MC. Reliability and minimal detectable change of the weight-bearing lunge test: A systematic review. Man Ther 2015;20(4):524-32.
65. Dennis RJ, Finch CF, Elliott BC, Farhart PJ. The reliability of musculoskeletal screening tests used in cricket. Phys Ther Sport 2008;9(1):25-33.
66. Teyhen DS, Shaffer SW, Lorenson CL, Halfpap JP, Donofry DF, Walker MJ, et al. The Functional Movement Screen: a reliability study. J Orthop Sports Phys Ther 2012;42(6):530-40.
67. Gorman PP, Butler RJ, Plisky PJ, Kiesel KB. Upper Quarter Y Balance Test: reliability and performance comparison between genders in active adults. J Strength Cond Res 2012;26(11):3043-8.
68. Plisky PJ, Gorman PP, Butler RJ, Kiesel KB, Underwood FB, Elkins B. The reliability of an instrumented device for measuring components of the star excursion balance test. N Am J Sports Phys Ther 2009;4(2):92-9.
69. Gribble PA, Kelly SE, Refshauge KM, Hiller CE. Interrater reliability of the star excursion balance test. J Athl Train 2013;48(5):621-6.
70. Portney LG, Watkins MP. Foundations of clinical research : applications to practice. 3rd ed. Upper Saddle River, N.J.: Pearson/Prentice Hall; 2009.

71. Bodden JG, Needham RA, Chockalingam N. The effect of an intervention program on functional movement screen test scores in mixed martial arts athletes. J Strength Cond Res 2015;29(1):219-25.
72. Cibulka MT, Sinacore DR, Cromer GS, Delitto A. Unilateral hip rotation range of motion asymmetry in patients with sacroiliac joint regional pain. Spine (Phila Pa 1976) 1998;23(9):1009-15.
73. Harris-Hayes M, Sahrmann SA, Van Dillen LR. Relationship between the hip and low back pain in athletes who participate in rotation-related sports. J Sport Rehabil 2009;18(1):60-75.
74. Warren M, Smith CA, Chimera NJ. Association of the Functional Movement Screen with injuries in division I athletes. J Sport Rehabil 2015;24(2):163-70.
75. Shumway-Cook A, Woollacott MH. Motor control : translating research into clinical practice. 4th ed. Philadelphia: Wolters Kluwer Health/Lippincott Williams & Wilkins; 2012.
76. Wainner RS, Whitman JM, Cleland JA, Flynn TW. Regional interdependence: a musculoskeletal examination model whose time has come. J Orthop Sports Phys Ther 2007;37(11):658-60.
77. Bialosky JE, Bishop MD, Price DD, Robinson ME, George SZ. The mechanisms of manual therapy in the treatment of musculoskeletal pain: a comprehensive model. Man Ther 2009;14(5):531-8.
78. Gallois M, Davergne T, Ledinot P, Ravaud P, Regnaux JP. Dosage of preventive or therapeutic exercise interventions: review of published randomized controlled trials and survey of authors. Arch Phys Med Rehabil 2017.

Dissertation Vita

Kate Schwartzkopf-Phifer, DPT, OCS, CSCS

Education:

PhD Rehabilitation Sciences (Anticipated graduation: Fall 2017)
University of Kentucky, College of Health Sciences
Lexington, KY—August 2013-Current

Doctor of Physical Therapy
Regis University, Rueckert-Hartman College of Health Professions
Denver, CO—December 2009

Orthopedic Physical Therapy Residency
Evidence in Motion
Louisville, KY—December 2009

Master and Bachelor of Physical Therapy
University of Evansville, College of Education and Health Sciences
Evansville, IN—May 2007

Employment:

University of Evansville (Evansville, IN)
Title: Assistant Professor
August 1, 2015-Current (Adjunct from August 2012-May 2015)

Rehabilitation and Performance Institute, PSC (Owensboro, KY)
Title: Staff Physical Therapist
September 20, 2016-Current

Rocky Mountain University of Health Professions (Provo, UT)
Title: Adjunct Faculty for Doctor of Health Sciences Program
January 1, 2016-Current

ProRehab, PC (Evansville, IN)
Title: Staff Physical Therapist
March 2008-June 2016

ProgressiveHealth of Indiana, Evansville, IN
Title: Staff Physical Therapist
May 2007-March 2008

Publications:

Schwartzkopf-Phifer KB and Kiesel KB (2014). Functional movement tests and injury risk in athletes. *Lower Extremity Review, July 2014*. Retrieved from http://lermagazine.com/article/functional-movement-tests-and-injury-risk-in-athletes

____Kathryn Schwartzkopf-Phifer_____
Student Name