ORIGINAL ARTICLE

IJPHY

Utilizing a Trunk Control Strategy versus Standard Hip-Focused Exercises: Effects on Lower Extremity Kinematics in a Pilot Randomized Controlled Trial

[1,3]Dischiavi, S.L., PT, PhD, DPT, MPT, SCS, ATC, COMT, Cert DN
[2]Wright, A.A., PT, PhD, DPT, OCS, FAAOMPT
[3]McCabe, C., PhD, BSc, SFHEA
[3]Bleakley, C.M., PT, PhD, BSc, MCSP, SRP

ABSTRACT

Background: Anterior Cruciate Ligament (ACL) injuries can have devastating consequences, including long rehabilitation periods and high costs. Despite advances in rehabilitation, long-term outcomes remain poor. This study explores using a trunk control exercise strategy aimed at controlling kinematic variables that are key risk factors for ACL injuries.

Methods: A prospective pilot randomized controlled superiority trial. Baseline included 30 healthy female participants. Outcome measures included 2D video analysis, single-leg squat, drop-jump landing testing, and peak isometric/isokinetic torque of the hip muscles. Data were tested for normality; parametric tests were used as appropriate. Thirty recreationally active females participated in the study. Fifteen participants attended eighteen sessions over six weeks and performed either trunk control or basic hip exercises.

Results: All participants (30/30) completed the training interventions. Baseline characteristics were comparable between the experimental and control groups. Running analysis revealed mostly negligible differences in effect sizes for joint angles between groups, with minor trends favoring the EG for several lower extremity kinematics. Single-leg squat (SLS) performances favored the control group, whereas the vertical drop jump (DVJ) favored the experimental group. Isometric and isokinetic strength tests favored the experimental group, particularly for hip external rotation. However, local and summated joint angle analysis revealed a moderate effect for the EG in the dominant right lower extremity during the single-leg drop vertical jump.

Conclusion: The findings suggest that task-specific neuromuscular control during single-leg landing maneuvers can be influenced by targeted trunk control exercises, with potential implications for ACL injury prevention programs and rehabilitation.

Trial Registration: ClinicalTrials.gov: NCT03285464. Registered 23 Feb 2018 (retrospectively registered).

Keywords: Anterior Cruciate Ligament, Exercise, Hip, Knee, Prevention, Rehabilitation.

Received 14th January 2026, accepted 18th May 2026, published 09th June 2026

www.ijphy.com

DOI : 10.15621/ijphy/2026/v13i2/2181

[1]Department of Physical Therapy, Hybrid DPT MUSC, Charleston, SC.
[2]Department of Public Health and Community Medicine, School of Medicine, Tufts University, 136 Harrison Ave, Boston, MA, 02111, USA.
[3]Sport and Exercise Sciences Research Institute, School of Sport, Ulster University, Carrickfergus, Newtownabbey, County Antrim, UK.

CORRESPONDING AUTHOR

[1,3]Dischiavi, S.L., PT, PhD

Medical University of South Carolina, MUSC
Hybrid DPT Program, 151- A Rutledge Avenue
Charleston, SC 29425.
P: (843) 619-2074
E-Mail: dischiav@musc.edu

INTRODUCTION

Knee injuries are highly prevalent in athletic populations, with anterior cruciate ligament (ACL) injuries being among the most common [1, 2]. Female athletes are disproportionately affected, with epidemiological studies showing a 2 to 10-times higher risk compared to males [3-6]. Long-term outcomes remain poor, with re-injury rates between 25–33%, and nearly half of patients fail to return to pre-injury activity levels [7, 8] [9, 10]. Despite extensive research and prevention efforts, ACL injury rates and recurrence remain high [11-15], underscoring the need to optimize therapeutic exercise strategies [16].

Current ACL injury prevention programs often target dynamic knee valgus (DKV), a key modifiable risk factor in ACL injury etiology [17]. DKV involves complex, multiplanar movements, including hip internal rotation, adduction, and knee abduction [18-20], contributing to medial knee displacement and increased injury risk [21]. Hip-focused training has been central to controlling DKV, emphasizing the role of the hip musculature in stabilizing lower-limb kinematics. However, recent evidence suggests that injury mechanisms often involve perturbations of the trunk prior to high-speed, single-leg landings, indicating that proximal control should extend beyond the hip to include trunk dynamics [12, 22, 23].

A recent scoping review of ACL prevention programs revealed that exercises are often simplified for replication and target isolated segments of the kinetic chain [24]. While this approach facilitates clinical implementation, it may lack the complexity needed to challenge motor learning and reflect real-world injury scenarios. Presented here is a novel intervention strategy that leverages trunk dynamics to modulate lower extremity loading, using the trunk as a biomechanical lever to introduce controlled perturbations. By using the trunk as a lever and a source of perturbation, this novel method promotes whole-body coordination and reactive control, aligning with contemporary injury-prevention goals that prioritize movement quality and motor learning over isolated strength. This randomized controlled pilot study aimed to quantify the effects of a single-leg landing using a trunk-control strategy on hip strength and trunk-lower-extremity kinematic control in recreationally active females. We compared this novel approach to a basic intervention representative of current practice. Outcomes included 2D kinematic assessments during running and performance tasks such as single-leg squats and drop vertical jumps. Secondary objectives included evaluating participant adherence and retention and identifying the most responsive outcome measures to inform future trial design.

METHODOLOGY

Study Design

This was a prospective, randomized, controlled superiority pilot trial. Participants underwent baseline testing of biomechanics and strength. Completed a 6-week intervention and were retested. All data collection occurred within the High Point Biomechanics and Physiology Lab. The study protocol was approved by the Institutional Review Board at High Point University (HPU) (protocol number: 201508-387). The study protocol was recorded on ClinicalTrials.gov (NCT03285464). Documentation and reporting of the randomized controlled trial adhered to CONSORT (Consolidated Standards of Reporting Trials) standards (Fig. 1) [25, 26]. All participants received a detailed explanation of the experimental procedures and possible risks, and provided written informed consent before testing.

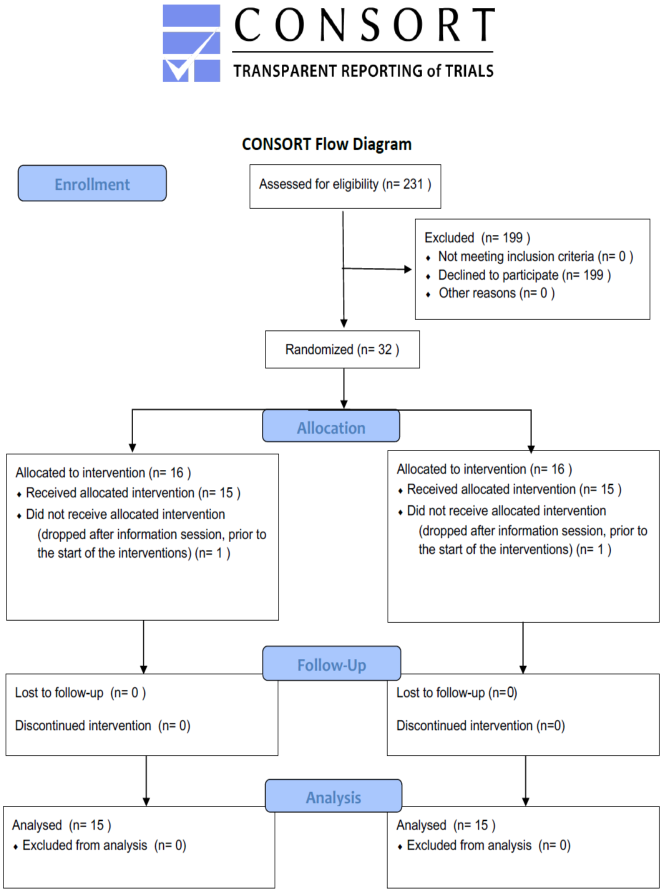


Figure 1: CONSORT Diagram

Participants

The study sample was drawn from recreational female athletes enrolled at the High Point University campus, who were actively recruited to participate. The research project was presented to 231 potential research participants at the university. 32 female participants met the research criteria. Inclusion criteria consisted of female participants undertaking pain-free recreational running at least twice per week. Individuals were deemed ineligible if they reported an injury to the low back, pelvic region, or lower extremity within three months before participation [27]. A past surgical history involving the low back, pelvis, or lower extremity constituted an additional exclusion criterion. The initial 32 volunteer participants were randomly allocated into two groups: 1) an experimental group (EG; n=16) and 2) a control group (CG; n=16). A computerized randomization process was used to assign participants to experimental or control groups, ensuring concealed allocation and minimizing potential selection bias. Two enrolled participants discontinued participation before baseline testing. The final analyzed sample consisted of 30 participants, evenly distributed between the experimental and control groups, all of whom completed the 6-week exercise program.

Materials

2D Video Analysis

Video recordings were uploaded into Dartfish (Version 9, Dartfish, Fribourg, Switzerland) for post-processing, after which three kinematic variables were quantified for each trial. These measures included lateral trunk motion (LTM), maximum hip adduction angle (HADD), and peak knee valgus angle (KV) (Fig. 2). Two-dimensional (2D) video was captured with a standard video camera (Sony Corporation, Tokyo, Japan). Two-dimensional video analysis employing the frontal plane projection angle (FPPA) has been shown to provide reliable and accurate measures of lower extremity kinematics in single-leg athletic activities [28, 29].

In addition to the LTM, HADD, and KV primary angle measurements, summated angles were also captured. Summated joint angles were calculated by adding the values of either all three variables or by combining pairs of the individual joint angles. Composite (summated) angle scores were calculated to represent aggregate changes in regional and global positioning across testing sessions. These scores were constructed from validated and reliable kinematic measures of the trunk, hip, and knee [30-33].

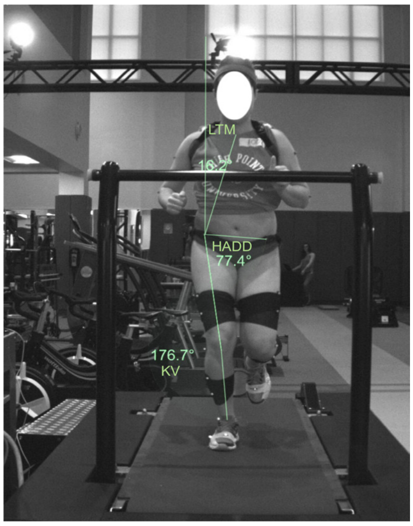


Figure 2: 2D video analysis angles

Exercise Training Interventions

The exercise interventions took place in the HPU Biomechanics Lab. Across both groups, the intervention was performed three times weekly for six weeks, with two sessions conducted under supervision and one completed independently. This schedule yielded a total of 18 exercise sessions per participant. Sessions took place on non-consecutive days to allow for adequate recovery. Throughout the intervention, each group performed two weekly exercises involving both limbs. Over the six weeks, participants completed 12 exercises across 18 exercise sessions. A detailed outline of the intervention schedule has been provided, which includes exercise titles, corresponding sets, repetitions, and progressions (Appendix 1).

Control Group Exercises

The control intervention consisted of hip-strengthening exercises commonly cited in the literature. These exercises were representative of current clinical research practices. They emphasized straightforward movement patterns that were primarily single-plane, slow in execution, and initially performed without weight bearing. The control exercise protocol consisted of two phases: an initial two-week period emphasizing non-weight-bearing and local hip muscle exercises, followed by a four-week progression to weight-bearing exercises. The entire control group's program was provided with each week's exercises, accompanied by pictures of the starting and ending positions for each exercise (Appendix 2).

Experimental Group Exercises

The experimental group followed a trunk control exercise protocol specifically developed for this investigation. Exercises were executed on both lower extremities and utilized the trunk as the primary lever for delivering resistance to the hip musculature [34]. In alignment with current evidence of trunk perturbations being involved in ACL injury mechanisms, each of the exercises utilized in this pilot study has been peer-reviewed and published in an earlier feasibility study [35]. The experimental group's exercises have been provided with pictures demonstrating the starting and ending positions for each exercise (Appendix 3).

Procedures

Outcome Measures

Treadmill Running

Frontal-plane trunk position, hip adduction, and knee valgus angles were captured at self-selected and prescribed speeds on a custom-built treadmill (Treadmetrix, Park City, UT, USA). An exact target speed of 3.58 m/s was specified in advance and implemented for the trial conducted immediately after the self-selected condition [36]. A 1-minute trial was collected at each speed using 2D video collection methods.

Single Leg Squat

Before testing, standardized instructions were shared with each participant. The non-weight-bearing limb was placed posterior to the weight-bearing limb to simulate the reciprocal mechanics of running. Participants performed the task at a prescribed tempo of 2 seconds for descent and 2 seconds for ascent, with the arms kept overhead. Knee flexion depth was standardized through a demonstration illustrating 75 degrees of flexion during the squat [31].

Single Leg Drop Vertical Jump

The task was initiated from a 30-cm box, where participants stood on a single limb and performed a diagonal drop to the floor anterior to the box, landing contralateral to the tested extremity. Trials were deemed invalid if the non-weight-bearing limb contacted the ground. Participants were required to maintain post-landing balance for 2 seconds, with three acceptable trials recorded for each limb.

Isometric/Isokinetic Hip Strength

Hip muscle strength testing focused on isometric assessments of abduction, extension, and external rotation. These muscle groups were chosen based on established links between hip weakness and injury risk in ACL populations [37]. Participants were instructed to generate maximal voluntary isometric force against a hand-held dynamometer (MicroFET 3; Hoggan Scientific, Salt Lake City, UT) [38]. This device, previously shown to be reliable [38], was selected to maintain a clinically pragmatic testing approach that is consistent with real-world equipment and time constraints. Measurement of hip extension torque was also performed using an isokinetic dynamometer (Humac NORM, CSMi, Stoughton, MA, USA).

Data Analysis

For the primary analysis, change scores were calculated for each numerical variable by subtracting pre-intervention values from post-intervention values. Effect sizes, using Cohen's d with 95% confidence intervals, were then calculated to compare the change scores between the trunk control group and the basic group. Effect sizes were interpreted using Cohen's guidelines, where values less than 0.2 were considered small, between 0.2 and 0.5 were classified as medium, and those greater than 0.8 were deemed large. In line with the study's pilot nature, no inferential statistical tests were performed. For the secondary objective, adherence and retention rates were compared against pre-specified thresholds, with 90% adherence and retention considered a success. This meant that at least 90% of participants in the intervention group were expected to follow the prescribed exercise protocol and complete both pre- and post-intervention assessments.

Separate forest plots were created for each performance task (e.g., single-leg squat, single-leg drop vertical jump, running kinematics, and strength) to illustrate the magnitude and direction of the effects for each outcome. These effect sizes were also used to estimate sample sizes for each performance task, with 80% power and a 5% alpha level, calculated in SPSS. It was also important to examine the data to quantify the typical variation in summated angles, a key measurement that is often underreported in the literature. Adherence, retention rates, and sample size estimates will collectively guide the decision on whether to proceed with a fully powered trial.

RESULTS

All enrolled participants completed the full six-week intervention and were included in the final analyses (n=30). No adverse events occurred during the study period.

Baseline Characteristics

Comparisons between groups revealed no statistically significant differences in demographic or training variables, including age, stature, body mass, body mass index, and weekly running mileage or speed (Table 1). Assessment of limb dominance showed that 29 out of the 30 participants identified the right lower extremity as the dominant limb for landing, based on kicking preference.

Table 1: Study group demographics

	CONTROL GROUP n= 15	EXPERIMENTAL GROUP n=15
AGE (years)	21.1 ± 1.9	20.9 ± 1.8
Height (cm)	163.7 ± 5.7	163.5 ± 6.0
Weight (kg)	61.1 ± 7.7	65.4 ± 14.3
BMI (kg/m2)	22.9 ± 3.2	24.2 ± 3.9
Miles Per Week	3.8 ± 4.1	2.6 ± 2.3
SS Run Speed	6.4 ± .78	6.2 ± .82
Leg Dominance	R= 14; L= 1	R= 15; L= 0

2D Kinematics

Running at Self-Selected (SS) & Prescribed Speed (Rx)

Cohen's d effect sizes were negligible (<0.20) for isolated 2D variables LTM, HADD, and KV, as well as all three variables summated and the two variable combinations. The only small effect size (d=0.21) was for the isolated variable hip adduction (HADD) at the prescribed (Rx) running speed of the dominant right lower extremity, favoring the experimental group (Fig. 3).

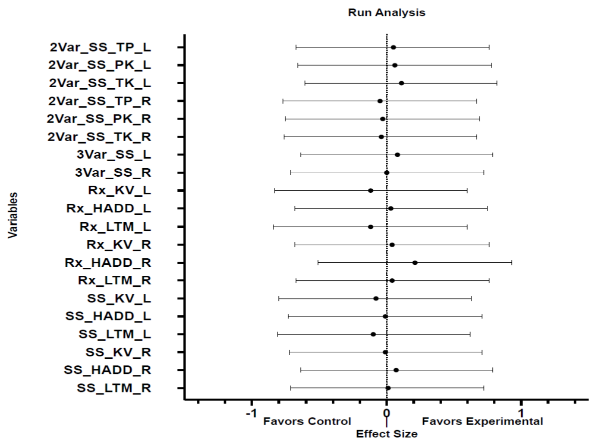


Figure 3: Run Analysis

Single Leg Squat (SLS)

Moderate to large Cohen's d effect sizes were observed favoring the control group for the dominant right lower extremity for the isolated variables of hip adduction (HADD) (d=0.65) and knee valgus (KV) (d=0.70). There was also a small effect (d=0.24) observed for controlling hip adduction of the left lower extremity during the single-leg squat. All remaining variables for the SLS were of negligible effect (<0.20) (Fig. 4).

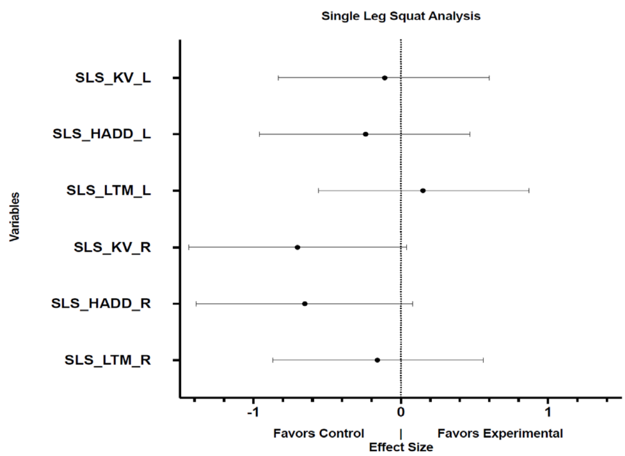


Figure 4: Single Leg Squat Analysis

Single Leg Drop Vertical Jump (DVJ)

The single-leg drop vertical jump showed the most variables, with small to moderate effects, mostly favoring the experimental group. These effects were noted at the isolated variables for both the dominant right (HADD d=0.22; KV d=0.30) and the left (LTM d=0.24; HADD d=0.20) lower extremity. Both the right and left lower extremities for the 3 summed variables favored the experimental group, with a small to moderate effect noted on the right (d=0.33). All 2-variable combinations favored the experimental group on the right (TK d=0.32; PK d=0.34; TP d=0.26) and one on the left (TP d=0.23). All remaining variables favored the experimental group, except left knee valgus, which favored the control group (d < .20) (Fig. 5).

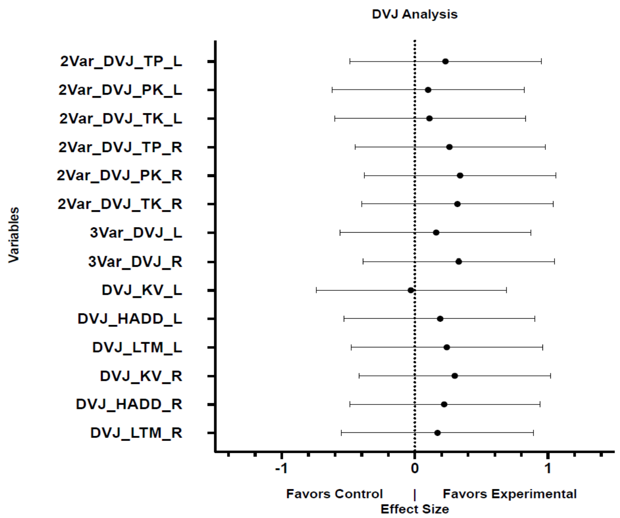


Figure 5: Drop Vertical Jump Analysis

Kinematic outcomes for the dominant right lower extremity are additionally illustrated in a scatter plot depicting the relationship between pelvic and knee variables on the right stance limb for participants in the control and experimental groups. The experimental scores are clustered in the upper-right quadrant, suggesting that the trunk control exercises have affected the knee valgus and hip adduction variables, favoring the exercise group using the trunk control strategies (Fig. 6).

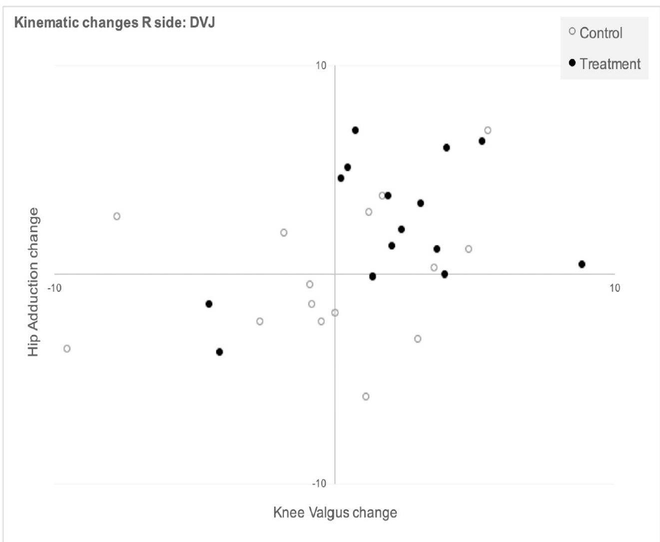


Figure 6: Scatter Plot

Isometric/Isokinetic Strength

Regarding isometric strength testing, the left hip extension favored the control group (d=0.30). Small effects were observed in isometric strength for ER on the right (d=0.29) and left (d=0.25) sides, both favoring the experimental group. A small to moderate effect was observed during isokinetic concentric testing on the left (d=0.31). The remaining isokinetic tests had negligible effects and favored the experimental group, except for isometric outcomes for right-sided abduction and extension, which favored the control (d < .20) (Fig. 7).

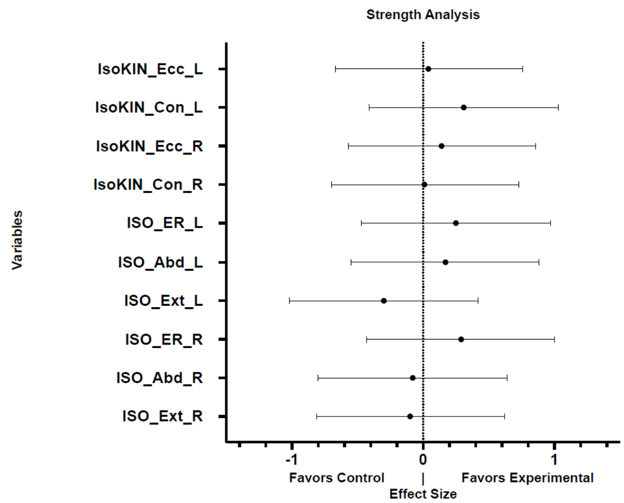


Figure 7: Strength Analysis

Sample Size Calculation

The most consistent effects favoring the trunk control intervention were observed in both the summated and isolated joint angles during the single-leg drop vertical jump. The largest difference in favor of the trunk control intervention was a mean difference of 5 degrees, with a pooled SD of 11.8. Based on the observed effect size and assuming Type I and Type II error rates of 5% and 20%, respectively, a fully powered randomized controlled trial would require a minimum of 72 participants per group to detect statistical significance.

DISCUSSION

This pilot randomized controlled trial examined whether a trunk-focused exercise program, compared with traditional hip-strengthening exercises, influenced global two-dimensional kinematic patterns during running and selected functional tasks in recreationally active females. The study aimed to advance current intervention strategies, which are often reductionist and rely on single-plane, slow-velocity concentric exercises performed in nonfunctional positions [24]. The hypothesis was that trunk control exercises would demonstrate an increase in their effectiveness at altering kinematics in female recreational athletes. Basic control group exercises showed improvement in the single-leg squat, while trunk control exercises improved dynamic kinematics, particularly during the single-leg drop vertical jump (SLDVJ). The findings suggest that trunk control exercises may influence complex, task-specific neuromuscular control movements and may optimize kinetic chain alignment during single-leg landings, a key element in the ACL mechanism of injury.

The greatest between-group differences were observed during assessments involving more dynamic tasks. These tasks can be characterized as feedforward in nature, requiring anticipatory control in preparation for an impending perturbation, such as a single-leg landing, where limited time is available for motor planning and self-organization [39]. These types of dynamic feedforward movements are a unique construct where the nervous system has less time to control or correct movements, such as limb position in space during a single leg landing [39]. As a task, the single-leg drop vertical jump (SLDVJ) involves greater movement complexity and anticipatory control, driven by the need to manage a rapid eccentric landing. By comparison, the single-leg squat is executed at a slower pace, is largely single-plane, and depends more on feedback mechanisms than on feedforward neuromuscular strategies.

Both limbs were analyzed during the SLDVJ, with measurements obtained for trunk positioning, hip adduction, and dynamic knee valgus. The trunk control strategy intervention outperformed the comparison condition in 13 of 14 potential outcome variables during the drop vertical jump task. Changes were disproportionately observed in the right lower extremity, with the dominant side demonstrating a larger effect size for knee valgus compared with the nondominant side. Consistent with this finding, 29 of 30 participants identified the right limb as dominant. Prior literature suggests that dominant limbs preferentially govern anticipatory, feedforward movement trajectories. In contrast, nondominant limbs tend to rely more heavily on feedback-based mechanisms for positional control, which may help explain the observed side-specific effects [40].

The trunk control intervention targeted the task-specific responses required during single-leg landing activities. A longer training duration may have allowed for greater neuromuscular adaptation than was observed within the six-week timeframe. The use of task-specific movements, including jump landing exercises, may therefore explain the between-group differences noted during the SLDVJ. This interpretation is supported by existing literature, as a recent meta-analysis reported an association between hip weakness and knee valgus during single-leg landings [18], suggesting a need for control strategies that provide a motor control and strength focus to effectively decelerate the eccentric valgus collapse of the lower extremity during single limb ground impacts.

Research has suggested that targeted interventions need to be designed to address suboptimal movement-related risk factors [30]. To our knowledge, this investigation is the first to examine global movement patterns using a composite measure integrating trunk, pelvic, and lower extremity segments derived from two-dimensional video analysis following a trunk control-based exercise intervention. The preliminary effect sizes observed in this study, coupled with the demonstrated compliance and retention of the participants, are a promising first step toward illustrating that moving toward more targeted trunk control interventions can positively impact complex movement patterns across the global kinetic chain.

Several limitations should be acknowledged. Two-dimensional video analysis may be limited in accurately capturing transverse-plane motion, and future investigations may benefit from three-dimensional motion capture techniques to better quantify rotational kinematics. In addition, kinetic variables, such as ground reaction forces, were not measured, and incorporating force plate data in future studies could provide additional insight into movement mechanics.

CONCLUSION

Results from this study suggest that isolated strengthening exercises do not substantially alter kinematics in recreationally active female populations. Improvements were more apparent in tasks that emphasized dynamic, high-speed motor control demands, including single-leg landing activities. Considering the complex and multifaceted etiology of lower extremity injury, along with the lack of agreement on a definitive exercise prescription, these findings highlight an opportunity to design trunk control interventions that more closely match the complexity of real-world athletic movement. Further research is warranted to assess the effectiveness of these trunk control exercises in more elite athletic populations with higher, more complex movement demands.

Acknowledgment: The data presented in this manuscript were derived from the research conducted during the author's (SLD) PhD research.

REFERENCES

[1] Majewski, M., H. Susanne, and S. Klaus, Epidemiology of athletic knee injuries: A 10-year study. Knee, 2006. **13**(3): p. 184-8.

[2] Steinbruck, K., [Epidemiology of sports injuries--25-year-analysis of sports orthopedic-traumatologic ambulatory care]. Sportverletz Sportschaden, 1999. **13**(2): p. 38-52.

[3] Myer, G.D., et al., Sport Specialization, Part I: Does Early Sports Specialization Increase Negative Outcomes and Reduce the Opportunity for Success in Young Athletes? Sports Health, 2015. **7**(5): p. 437-42.

[4] Bulow, A., et al., Lower Extremity Kinematics of the Y-Balance Test in Healthy and ACL Injured Adolescent Females. Int J Sports Phys Ther, 2021. **16**(2): p. 381-392.

[5] Larwa, J., et al., Stiff Landings, Core Stability, and Dynamic Knee Valgus: A Systematic Review on Documented Anterior Cruciate Ligament Ruptures in Male and Female Athletes. Int J Environ Res Public Health, 2021. **18**(7).

[6] Marmura, H., D.M. Bryant, and A.M. Getgood, Infographic. Sex differences and ACL injuries. Br J Sports Med, 2021.

[7] Schilaty, N.D., et al., Incidence of Second Anterior Cruciate Ligament Tears (1990-2000) and Associated Factors in a Specific Geographic Locale. Am J Sports Med, 2017. **45**(7): p. 1567-1573.
[8] Shultz, S.J., et al., Anterior Cruciate Ligament Research Retreat VIII Summary Statement: An Update on Injury Risk Identification and Prevention Across the Anterior Cruciate Ligament Injury Continuum, March 14-16, 2019, Greensboro, NC. J Athl Train, 2019. **54**(9): p. 970-984.
[9] Ardern, C.L., et al., Fifty-five per cent return to competitive sport following anterior cruciate ligament reconstruction surgery: an updated systematic review and meta-analysis including aspects of physical functioning and contextual factors. Br J Sports Med, 2014. **48**(21): p. 1543-52.
[10] Huang, Y.L., et al., A Majority of Anterior Cruciate Ligament Injuries Can Be Prevented by Injury Prevention Programs: A Systematic Review of Randomized Controlled Trials and Cluster-Randomized Controlled Trials With Meta-analysis. Am J Sports Med, 2020. **48**(6): p. 1505-1515.
[11] Agel, J., T. Rockwood, and D. Klossner, Collegiate ACL Injury Rates Across 15 Sports: National Collegiate Athletic Association Injury Surveillance System Data Update (2004-2005 Through 2012-2013). Clin J Sport Med, 2016.
[12] Della Villa, F., et al., Systematic video analysis of ACL injuries in professional male football (soccer): injury mechanisms, situational patterns and biomechanics study on 134 consecutive cases. Br J Sports Med, 2020. **54**(23): p. 1423-1432.
[13] Kaeding, C.C., B. Leger-St-Jean, and R.A. Magnussen, Epidemiology and Diagnosis of Anterior Cruciate Ligament Injuries. Clin Sports Med, 2017. **36**(1): p. 1-8.
[14] Padua, D.A., et al., National Athletic Trainers' Association Position Statement: Prevention of Anterior Cruciate Ligament Injury. J Athl Train, 2018. **53**(1): p. 5-19.
[15] Webster, K.E. and T.E. Hewett, Meta-analysis of meta-analyses of anterior cruciate ligament injury reduction training programs. J Orthop Res, 2018. **36**(10): p. 2696-2708.
[16] Taylor, J.B., et al., A 6-week warm-up injury prevention programme results in minimal biomechanical changes during jump landings: a randomized controlled trial. Knee Surg Sports Traumatol Arthrosc, 2018. **26**(10): p. 2942-2951.
[17] Ford, K.R., et al., An evidence-based review of hip-focused neuromuscular exercise interventions to address dynamic lower extremity valgus. Open Access J Sports Med, 2015. **6**: p. 291-303.
[18] Dix, J., et al., The relationship between hip muscle strength and dynamic knee valgus in asymptomatic females: A systematic review. Phys Ther Sport, 2019. **37**: p. 197-209.
[19] Hewett, T.E., et al., Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. Am J Sports Med, 2005. **33**(4): p. 492-501.
[20] Paz, G.A., et al., Kinematic Analysis of Knee Valgus during Drop Vertical Jump and Forward Step-up in Young Basketball Players. Int J Sports Phys Ther, 2016. **11**(2): p. 212-9.
[21] Hewett, T.E. and G.D. Myer, The mechanistic connection between the trunk, hip, knee, and anterior cruciate ligament injury. Exerc Sport Sci Rev, 2011. **39**(4): p. 161-6.
[22] Andersen, H.A., The history of reductionism versus holistic approaches to scientific research. Endeavour, 2001. **25**(4): p. 153-156.
[23] Corning, P.A., Synergy and self-organization in the evolution of complex systems. Systems Research and Behavioral Science, 1995. **12**(2): p. 89-121.
[24] Dischiavi, S.L., et al., Do ACL Injury Risk Reduction Exercises Reflect Common Injury Mechanisms? A Scoping Review of Injury Prevention Programs. Sports Health, 2021: p. 19417381211037966.
[25] Eldridge, S.M., et al., CONSORT 2010 statement: extension to randomised pilot and feasibility trials. Pilot Feasibility Stud, 2016. **2**: p. 64.
[26] Eldridge, S.M., et al., Defining Feasibility and Pilot Studies in Preparation for Randomised Controlled Trials: Development of a Conceptual Framework. PLoS One, 2016. **11**(3): p. e0150205.
[27] Dingenen, B., et al., Can two-dimensional video analysis during single-leg drop vertical jumps help identify non-contact knee injury risk? A one-year prospective study. Clin Biomech (Bristol, Avon), 2015. **30**(8): p. 781-7.
[28] Herrington, L. and A. Munro, Drop jump landing knee valgus angle; normative data in a physically active population. Phys Ther Sport, 2010. **11**(2): p. 56-9.
[29] Munro, A., L. Herrington, and M. Carolan, Reliability of 2-dimensional video assessment of frontal-plane dynamic knee valgus during common athletic screening tasks. J Sport Rehabil, 2012. **21**(1): p. 7-11.
[30] Dingenen, B., et al., Are two-dimensional measured frontal plane angles related to three-dimensional measured kinematic profiles during running? Phys Ther Sport, 2018. **29**: p. 84-92.
[31] Dingenen, B., et al., The reliability and validity of the measurement of lateral trunk motion in two-dimensional video analysis during unipodal functional screening tests in elite female athletes. Phys Ther Sport, 2014. **15**(2): p. 117-23.
[32] Dingenen, B., et al., Test-retest reliability of two-dimensional video analysis during running. Phys Ther Sport, 2018. **33**: p. 40-47.
[33] Kingston, B., et al., Validity and reliability of 2-dimensional trunk, hip, and knee frontal plane kinematics during single-leg squat, drop jump, and single-leg hop in females with patellofemoral pain.

Phys Ther Sport, 2020. **45**: p. 181-187.
[34] Dischiavi, S.L., et al., Framework for Optimizing Acl Rehabilitation Utilizing a Global Systems Approach. Int J Sports Phys Ther, 2020. **15**(3): p. 478-485.
[35] Dischiavi, S.L., A.A. Wright, and C.M. Bleakley, Feasibility and Acceptability of a 12-Week Advanced Hip-Focused Exercise Intervention Program for Female Athletes. Journal of Science in Sport and Exercise, 2023.
[36] Ford, K.R., et al., Relationship between hip strength and trunk motion in college cross-country runners. Med Sci Sports Exerc, 2013. **45**(6): p. 1125-30.
[37] Rinaldi, V.G., et al., The influence of gluteal muscle strength deficits on dynamic knee valgus: a scoping review. J Exp Orthop, 2022. **9**(1): p. 81.
[38] Thorborg, K., et al., Clinical assessment of hip strength using a hand-held dynamometer is reliable. Scand J Med Sci Sports, 2010. **20**(3): p. 493-501.
[39] Gokeler, A., et al., A novel approach to enhance ACL injury prevention programs. J Exp Orthop, 2018. **5**(1): p. 22.
[40] Promsri, A., et al., Leg Dominance Effects on Postural Control When Performing Challenging Balance *Exercises.* Brain Sci, 2020. **10**(3).

Appendix 1 : Intervention schedule & exercise

INTERVENTION SCHEDULE

	Visit 1	Visit 2	Visit 3	Visit 4	Visit 5
Session Week / Supervision	*Week 1 / Supervised*	*Week 1 / Supervised*	*Week 1 / Unsupervised*	*Week 2/ Supervised*	*Week 2/ Supervised*
CONTROL GROUP					
Exercise #1	Sidelying hip ER/Extension (max iso into wall) 2x10 / 5s	Sidelying hip ER/Extension (max iso into wall) 2x10 / 5s	Sidelying hip ER/Extension (max iso into wall) 2x10 / 5s	Resistance Band Clamshell 2x10	Resistance Band Clamshell 2x10
Exercise # 2	Hip ABD SLR Against wall 2 x 10 / 5s	Hip ABD SLR Against wall 2 x 10 / 5s	Hip ABD SLR Against wall 2 x 10 / 5s	Hip ABD SLR Against Wall 2 x 10 / 10s	Hip ABD SLR Against Wall 2 x 10 / 10s
Completed (YES or NO)	**Y OR N**	**Y OR N**	**Y OR N**	**Y OR N**	**Y OR N**
EXPERIMENTAL GROUP					
Exercise #1	Tall Kneel Band Drives w trunk rot pulls, banded clams, ½ roller 2 x 10 / 5s	Tall Kneel Band Drives w trunk rot pulls, banded clams, ½ roller 2 x 10 / 5s	Tall Kneel Band Drives w trunk rot pulls, banded clams, ½ roller 2 x 10 / 5s	Standing Band Drives w rotary resistance and banded clams 2 x 10 / 10s	Standing Band Drives w rotary resistance and banded clams 2 x 10 / 10s
Exercise # 2	Reverse Lunge w Rotary Resistance and running finish 2 x 10 / 5s	Reverse Lunge w Rotary Resistance and running finish 2 x 10 / 5s	Reverse Lunge w Rotary Resistance and running finish 2 x 10 / 5s	Single Leg Squat w rotary resistance 2 x 10 / 10s	Single Leg Squat w rotary resistance 2 x 10 / 10s
Completed (YES or NO)	**Y OR N**	**Y OR N**	**Y OR N**	**Y OR N**	**Y OR N**

INTERVENTION SCHEDULE

	Visit 6	Visit 7	Visit 8	Visit 9	Visit 10
Session Week / Supervision	*Week 2 / Unsupervised*	*Week 3 / Supervised*	*Week 3 / Supervised*	*Week 3 / Unsupervised*	*Week 4 / Supervised*
CONTROL GROUP					
Exercise #1	Resistance Band Clamshell 2x10	Bilateral Squat with Resistance Band Targeting HER 2 x 10 / 5s	Bilateral Squat with Resistance Band Targeting HER 2 x 10 / 5s	Bilateral Squat with Resistance Band Targeting HER 2 x 10 / 5s	Sidestepping with Resistance Band (HABD) 2 x 10 / Bil
Exercise # 2	Hip ABD SLR Against Wall 2 x 10 / 10s	Contralateral Pelvic Hike (HABD) against wall 2 x 10 / 5s	Contralateral Pelvic Hike (HABD) against wall 2 x 10 / 5s	Contralateral Pelvic Hike (HABD) against wall 2 x 10 / 5s	Single Leg Squat with Hand Support 2 x 10
Completed (YES or NO)	**Y OR N**	**Y OR N**	**Y OR N**	**Y OR N**	**Y OR N**
EXPERIMENTAL GROUP					
Exercise #1	Standing Band Drives w rotary resistance and banded clams 2 x 10 / 10s	Standing Band Drives w Rot Resistance Jumps and banded clams 2 x 10 / 5s	Standing Band Drives w Rot Resistance Jumps and banded clams 2 x 10 / 5s	Standing Band Drives w Rot Resistance Jumps and banded clams 2 x 10 / 5s	Bilateral Lateral Hops w Rotary Resistance and banded clams 2 x 10 / 5s
Exercise # 2	Single Leg Squat w rotary resistance 2 x 10 / 10s	Standing Rotary Step Outs 2 x 10 / 5s	Standing Rotary Step Outs 2 x 10 / 5s	Standing Rotary Step Outs 2 x 10 / 5s	Single Leg Squat w Rotary Resistance and Med/Lat Hops 2 x 10 /5s
Completed (YES or NO)	**Y OR N**	**Y OR N**	**Y OR N**	**Y OR N**	**Y OR N**

	Visit 16	Visit 17	Visit 18		
Session Week / Supervision	*Week 6 / Supervised*	*Week 6 / Supervised*	*Week 6 / Unsupervised*		
CONTROL GROUP					
Exercise #1	Standing Isometric HABD, HER Pelvic Hike Against Wall 2 x 10 / 10s	Standing Isometric HABD, HER Pelvic Hike Against Wall 2 x 10 / 10s	Standing Isometric HABD, HER Pelvic Hike Against Wall 2 x 10 / 10s		
Exercise # 2	Single Leg Squat with Resistance Band Targeting HABD 2 x 10	Single Leg Squat with Resistance Band Targeting HABD 2 x 10	Single Leg Squat with Resistance Band Targeting HABD 2 x 10		
Completed (YES or NO)	**Y OR N**	**Y OR N**	**Y OR N**		
EXPERIMENTAL GROUP					
Exercise #1	Single Leg Stance w Valgus Prevention w a Hop 2 x 10 / 5s	Single Leg Stance w Valgus Prevention w a Hop 2 x 10 / 5s	Single Leg Stance w Valgus Prevention w a Hop 2 x 10 / 5s		
Exercise # 2	Single Leg Squat with Rotary Resistance and Band at Knee 2 x 10 / 10s	Single Leg Squat with Rotary Resistance and Band at Knee 2 x 10 / 10s	Single Leg Squat with Rotary Resistance and Band at Knee 2 x 10 / 10s		
Completed (YES or NO)	**Y OR N**	**Y OR N**	**Y OR N**		

Appendix 2: Control group exercises

Control Group Exercises

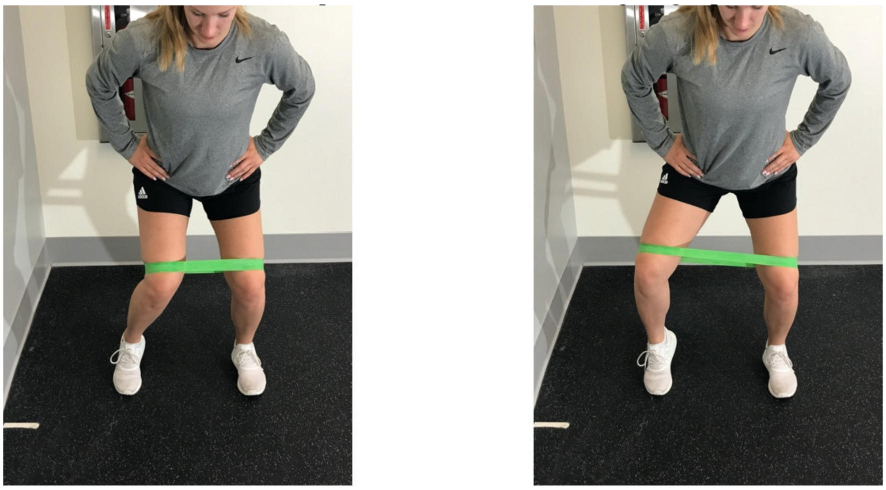
Week 1 – Exercise 1: Sidelying hip extension / ER (max wall isometric)

Week 1- Exercise 2: hip abduction straight leg raise against wall

Week 2- Exercise 1: Resisted clamshell exercise

Week 2- Exercise 2: Hip abduction straight leg raise against wall – longer hold

Week 3- Exercise 1: Bilateral squat with resistance band targeting hip external rotators



Week 3- Exercise 2: Contralateral pelvic hike (HABD) against the wall

Week 4- Exercise 1: Sidestepping with resistance band

Week 4- Exercise 2: Single leg squat with hand support

Week 5- Exercise 1: Standing isometric hip abduction and ER pelvic hike against the wall

Week 5- Exercise 2: Single leg squat without hand support

Week 6- Exercise 1: Standing isometric hip abduction and ER pelvic hike against the wall

Week 6- Exercise 2: Single leg squat with resistance band targeting hip abduction

Appendix 3: Experimental group exercises

Experimental Group

Week 1- Exercise 1: Tall kneel band drives with trunk rotation pulls – center, right, left

Week 1- Exercise 2: Reverse lunge with rotary resistance and running finish

Week 2- Exercise 1: Standing band drives with rotary resistance and banded clams

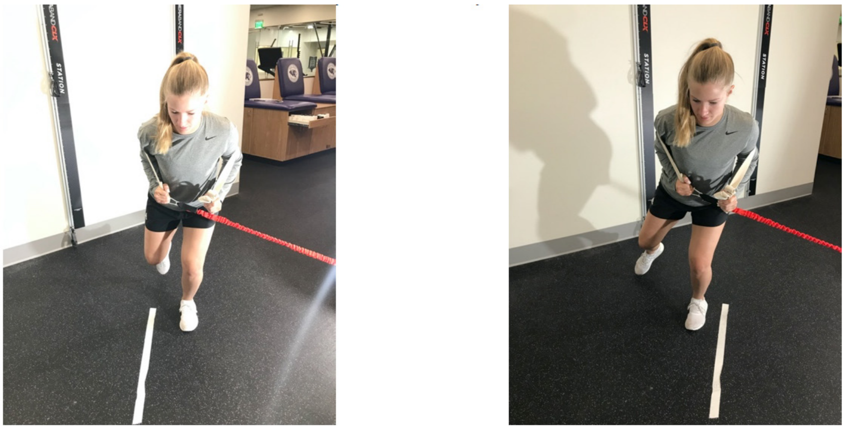
Week 2- Exercise 2: Single leg squat with rotary resistance

Week 3- Exercise 1: Standing band drives with rotary resistance jumps and banded clams

Week 3- Exercise 2: Standing rotary step outs

Week 4- Exercise 1: Bilateral lateral hops with rotary resistance and banded clams

Week 4- Exercise 2: Single leg squat with rotary resistance and medial / lateral hops



Week 5- Exercise 1: Single leg stance with valgus control

Week 5- Exercise 2: Single leg squat with rotary resistance and ¼ turn jumps

Week 6- Exercise 1: Single leg stance with valgus control with a hop

Week 6- Exercise 2: Single leg squat with rotary resistance and band at knee