EVALUATING THE EFFECTIVENESS OF AN INJURY PREVENTION WARM-UP FOR FEMALE COLLEGIATE SOCCER PLAYERS

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Neuromuscular training programs have been shown to decrease injury risk. The purpose of this study was to determine the effectiveness of a soccer-specific injury prevention warm-up program at improving game-time movement patterns. Acceleration and gyroscope data from IMUs and foot forces from smart insoles were collected in-the-field from 16 players during regularly scheduled soccer practice sessions. Change in impact and tibial anterior shear force, and lower extremity kinematics were compared throughout the season with a MANOVA. Tibial anterior shear force and acceleration, knee extension, and knee valgus decreased within each training session ($\Lambda = 0.387$, $F_{18,75} = 12.65$, $p < 0.01$), but not across the season ($\Lambda = 0.913$, $F_{5,18} = 0.34$, $p = 0.879$). This injury prevention warm-up program may be effective at modifying ACL injury risk factors in the short-term but not the long-term.

KEYWORDS: ACL, prehabilitation, IMU, smart insole.

INTRODUCTION: Soccer players can reduce their incidence of anterior cruciate ligament (ACL) tears by participating in injury prevention programs. ACL injury prevention programs are less effective for female soccer players than male soccer players (52% reduced risk versus 85% reduced risk, respectively), and female soccer players sustain ACL injuries at least four times more often than male soccer players (Sadoghi et al., 2012). These differences in injury incidence rate and injury prevention program effectiveness between male and female soccer players have been attributed to various factors, including anthropometrics, strength, neuromuscular control, program compliance, and skill transfer (Padua et al., 2018). It is important, therefore, to investigate the processes of ACL injury prevention programs designed for female soccer players to improve them based on evidence.
Many injury prevention programs incorporate neuromuscular-training and emphasize isolating and correcting movement patterns linked to ACL injury directly (Huang et al., 2020). The most common skills that female soccer players perform when they sustain an ACL injury are rapid deceleration with a change of direction, jump landing, and cutting manoeuvres (Alentorn-Geli et al., 2009). For those common skills, Yu and Garrett (2007) determined that great anterior tibial shear force and decreased knee flexion angle were the direct ACL injury risk factors, while Hewett et al. (2005) identified increased knee valgus with external rotation (termed dynamic valgus) as the direct ACL injury risk factors. Effective ACL injury prevention programs incorporate neuromuscular training designed to reduce anterior tibial shear force, increase knee flexion angle, and limit dynamic valgus.
An aim of the Marshall University Womens Soccer ACL injury prevention warm-up program (IPWUP) is to moderate the risk factors directly implicated in ACL injuries by coaching female soccer players to produce quality movement patterns as they perform a combination of flexibility, dynamic strength, plyometric, and potentiation exercises. This IPWUP's neuromuscular training occurs at the start of each soccer training session with the expectation that the quality movement patterns the soccer players are coached to produce during the warm-up will transfer to quality movement patterns during practice and game play. The transfer effects of the IPWUP to game-time movement patterns is unknown, however. Understanding the duration and extent of the neuromuscular-training effect of the IPWUP is crucial to evidence-based assessment and improvement of the program, and for increasing adherence by explaining to players the purpose and effects of the chosen exercises.
Biomechanical data collected in a laboratory setting is limited in that it does not reflect fully the movement patterns actually used during practice and play. Movement patterns used in practice and play settings are different to a lab due to differences in surface, visual environmental cues, arousal, and reactionary responses versus anticipatory instructions. Wearable technology

such as inertial measurement units (IMUs) can be valuable tools to collect biomechanical data that is more reflective of the practice and play movement patterns, especially when the wearable technology causes little interference in players' normal movements. Wearable technology, therefore, can be used to assess the effects of injury-prevention programs on game-time movements.
The purpose of this study was to determine the effectiveness of the IPWUP at improving game-time movement patterns over the course of a soccer season. We hypothesized that anterior tibial shear force, knee extension, knee valgus, and knee external rotation measured during game-time movements would be lower later in the season compared with early the season.

METHODS: With ethical approval and informed consent, sixteen female soccer players were recruited from an NCAA division one collegiate team (age: 19.7 ± 1.3 year, height: 1.66 ± 0.07 m, weight: 66.3 ± 7.8 kg) during their 14-week spring season. The players participated in practice sessions about three times per week, which consisted of skill drills, possession drills, and small-sided games, and competitive game play about once per two weeks throughout the season. The IPWUP was used before every practice session and game.
The IPWUP consisted of three parts: dynamic flexibility, strength & plyometric, and potentiation exercises, with all exercises performed as a series of shuttles over 20 meters, back and forth. The warm-up began with jogging, lateral shuffling, and backwards running, which was followed by dynamic stretches like walking kicks and quad pulls. The players then transitioned to strength exercises alternating with plyometric exercises, including skips for height, bounds for distance, accelerations and decelerations, unilateral and bilateral line hops, bodyweight squats, spider lunges, and good mornings. Each strength or plyometric exercise was performed for at least 10 repetitions. The warm-up concluded with potentiation exercises, during which the players responded to a verbal instruction or movement stimulus. For example, a player stands in the middle of four coloured cones, a colour is shouted at random, and the player must run to and touch the corresponding cone quickly before returning to the middle.
Once early and once late in their season, players wore pressure sensing Smart Insoles (ARION, Eindhoven) and wearable IMU's (Mbientlab Inc, San Francisco) during their entire practice session. The Smart Insoles were worn inside the players' cleats and recorded the normal forces (±2000N) applied at their feet at 120 Hz using ARION software. The IMU's were attached to the players' tibial tuberosities and lateral malleoli and recorded limb segment acceleration (±16g) and gyroscope (±2000°/s) data at 100 Hz using Mbientlab software. Distances were measured from the knee joint center to the IMU at the tibial tuberosity and from the lateral malleolus to the IMU at the foot. IMUs were placed so accelerations and angular velocities were recorded in a consistent limb reference frame of x-anterior, y-superior, z-lateral (right side). IMU and Smart Insole data were time synchronized using the global time-stamps of the hardware.
An anatomical neutral position was established for each athlete to set 0° limb segment angles. Angular velocities from the gyroscope were integrated and combined with the measured joint center-to-IMU distances to calculate 3-D lower extremity limb segment angles. An inverse dynamics approach was used to calculate resultant forces at the proximal tibia. The normal force from the Smart Insole was used as a distal, impact force input to a two-segment, rigid-link model of the foot and shank. Resultant forces and moments at the ankle of the foot segment were calculated using Newton's second law, the normal foot force, and IMU data for the foot. Resultant force and moment were transferred to the ankle of the shank segment using Newton's third law. Resultant forces and moments at the knee of the tibia segment were calculated using Newton's second law, the transferred ankle force and moment, and IMU data for the shank. The anterior directed component of the resultant force at the knee of the tibia segment was set to be the anterior tibial shear force.
Dependent variables that reflect ACL injury risk factors of anterior tibial shear force, impact force, resultant tibial acceleration, knee flexion angle, knee valgus angle, and knee external rotation angle were calculated as the average value of each variable within a 60 second window five minutes into the practice session (start) and again five minutes before the end of the practice session (end). A one-way repeated measured MANOVA with four levels of time:

early-start (early in season, start of practice), early-end (early in season, end of practice), late-start (later in season, start of practice), and late-end (later in season, end of practice) was used to assess changes in the dependent variables over time.

RESULTS: The sets of ACL injury risk factors were different among time points (Wilks' Λ = 0.387, $F_{18,75}$ = 12.65, p < 0.01, partial η^2 = 0.162). Planed multivariate follow-up tests compared the set of dependent variables between early-start and early-end (contrast A), between early-start and late-start (contrast B), and between late-start and late-end (Contrast C). The set of ACL injury risk factors during early-start differed in at least one dependent variable from early-end (Wilks' Λ = 0.028, $F_{5,18}$ = 122.81, p < 0.001; Table 1). There was no significant difference in the set of ACL injury risk factors between early-start and late-start (Wilks' Λ = 0.913, $F_{5,18}$ = 0.34, p = 0.879; Table 1). The set of ACL injury risk factors during late-start differed in at least one dependent variable from late-end (Wilks' Λ = 0.449, $F_{5,18}$ = 4.42, p < 0.01; Table 1).

Table 1: Discriminant Function Coefficients for Orthogonal Contrasts A, B, and C.

ACL Injury Risk Factor	Contrast A	Contrast B	Contrast C
Impact Force	-0.019	-0.033	-0.095
Anterior Tibial Shear Force	5.294	-0.164	4.608
Tibial Acceleration	4.640	-0.157	2.194
Knee Extension Angle	4.065	-0.971	2.605
Knee Valgus Angle	0.875	-0.093	0.250
Knee Internal Rotation Angle	0.975	0.021	0.296

A positive contrast weight means the dependent variable was greater in the first set of the comparison, and a negative weight means it was smaller in the first set.

A series of one-way ANOVAs for the six dependent variables were conducted as univariate follow-up tests. Post-hoc testing showed that anterior tibial shear force, resultant tibial acceleration, knee flexion, knee valgus, and knee external rotation were greater for early-start than either early-end (p < 0.01) or late-end (p < 0.01), but not late-start (Figure 1).

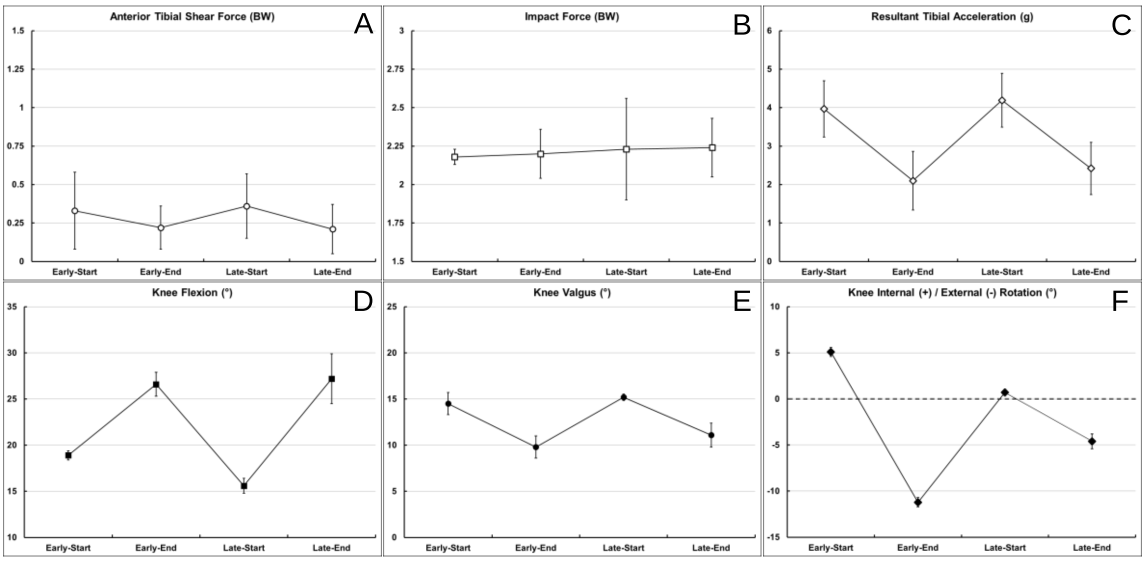

Figure 1 (A-F): Changes in ACL Risk Factors at Soccer Season/Session Time Levels

DISCUSSION: Our hypothesis that anterior tibial shear force, knee extension, knee valgus, and knee external rotation measured during game-time movements would be lower later in the season compared with early in the season was not supported. There was no significant difference in the set of ACL injury risk factors between early-start and late-start (contrast B). There was no long-term effect of the IPWUP. Anterior tibial shear force (Figure 1A), knee extension (Figure 1D), and knee valgus (Figure 1E) were lower at the end of a session both early and late in the season (contrasts A and C). These differences in ACL injury risk factors suggest that there may be a short-term effect of the IPWUP.

That ACL injury risk factors did not differ appreciably from early to late in the season but did decrease within a session (Figure 1) indicates poor skill retention. Worse retention is associated with coaching where instruction and feedback are provided constantly throughout the task, which is the coaching approach used as this IPWUP was implemented. Further, the soccer players in this study were practicing new movement patterns that were similar to their current movement patterns at the same time as learning new technical skills. Simultaneous learning of multiple motor skills may cause anterograde interference due to competition for memory storage in overlapping areas of the brain. A different instructional approach and longer implementation time may be needed for this IPWUP to have long-term effects similar to the short-term changes in ACL injury risk factors.

The decreases in anterior tibial shear force (Figure 1A), knee extension (Figure 1D), and knee valgus (Figure 1E) within sessions suggest that the IPWUP does have some short-term injury risk reduction effect. It is possible that these decreases from the start to end of a session were due to reduced effort and intensity, but this is unlikely, because the start of the sessions were mostly practice of technical skills, whereas the end of the sessions were mostly small-sided games where effort and intensity tended to be higher. The greater knee external rotation seen at the end of the sessions (Figure 1F) may also be the result of the practice session structure. Players were more likely to externally rotate at the knee during small-sided games as this position is necessary for the short, accurate passing that characterizes game play. The changes in ACL injury risk factors are associated with neuromuscular-training exercises that constitute the IPWUP. Skips, bounds, accelerations, and decelerations were chosen to reduce anterior tibial shear force by preparing the players to handle greater joint forces and knee extension by focusing players' attention on soft landings. Line hops were included for players to pay attention to minimizing dynamic knee valgus during landings. The beneficial short-term effects of the IPWUP supports the inclusion of these exercises into the program.

CONCLUSION: The injury prevention warm-up program was not successful at reducing anterior tibial shear force, knee extension, and knee valgus in the long-term, but there may be some short-term injury risk reduction effects.

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